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# A Human-Centred Approach for Residential Energy Efficiency Improving

Dissertação para a obtenção do grau de mestre
em Engenharia Electrotécnica e de Computadores

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*Follows a humble contribution*
*to help humanize technology*

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# Abstract

Smart-cities rely on enhancing the relationships between the actors that composes them so that their offered services grow in number, quality and efficiency. One of these actual services is the energy providing, which demand for efficiency puts it at the top of the list for an urgent smartening. It is estimated that the energy consumption in buildings accounts for 40% of the total energy needs in Europe. It also emerges as good fit for an internet-based solution due to its decentralized and heterogeneous profile. This fact has been acknowledged by the grid stakeholders, which are investing in the development of internet-based solutions for monitoring and controlling home appliances. But these solutions seem to be missing the technology's full potential to aggregate the grid with the consumers, as the former are not significantly responding to this call.

This work proposes a human-centred approach for this technology, by keeping the human in the loop and empowering its own smartening by using behavioural data instead of consumption data, and by bringing an emotional attachment to the task of improving households' consumption by *gamifying* the interface with this data. To achieve this goal a connected device and an online platform to support it were developed. A pilot stage to showcase the impact on refrigerators' usage, and consequently their consumption, was prepared, and preliminary results were gathered.

**Keywords:** smart-city, smart-home, internet-of-things, behaviour, *gamification*, human-centred design, big-data, energy, efficiency.

# Resumo

É estimado que 40% das necessidades de energia na Europa advêm do consumo de edifícios. É também reconhecido que o sector do consumo nos edifícios é dado a uma solução com base na Internet dadas as suas características de descentralização e heterogeneidade. Este facto foi reconhecido pela rede eléctrica, que tem investido no desenvolvimento de soluções de monitorização e controlo remotos do consumo de electrodomésticos com base na Internet. Mas estas soluções não estão a corresponder ao claro potencial desta tecnologia para agregar a rede com o consumidor, por falta de resposta do último.

Este trabalho propõe uma revisão desta tecnologia sob uma abordagem centrada no ser humano, que assenta na manutenção do utilizador no ciclo de ação na perspectiva de fazer dele próprio um agente mais inteligente ao recorrer a informação comportamental perante o desperdício energético em vez de a informação sobre o próprio consumo, e ao assinar um contrato emocional com a tarefa de melhorar estes comportamentos através da sua *gamificação*. Para atingir este objectivo foi desenvolvido um dispositivo de monitorização de comportamentos com impacto no consumo doméstico e uma plataforma online para o seu suporte. Foi preparado um projeto piloto para a validação do impacto do dispositivo na alteração comportamental dos utilizadores e, consequentemente, no seu consumo, sendo apresentados resultados preliminares deste piloto.

**Palavras-chave:** cidade-inteligente, casa-inteligente, internet-das-coisas, comportamento, *gamificação*, humanização, *big-data*, eficiência, energia.

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# Introduction

**Foreword**

"Smart" is undoubtedly a buzzword today. Things started to become "smart" in the mid-2000s with the revealing of the smart-phones. From that point forward the smart term got popular and the smart-tv, the smart-watch and the smart-home, among other smart-labelled things, came to be. With such over-usage the term started to derive from its meaning to become a simple label to technological evolutions of long settled first-world commodities. But this author would question if these things are really smart. To find the answer it would then be necessary to think about the definition of smart and its origin.

First of all smart, as a very fuzzy concept, should not be considered as an absolute, nor binary, measurement. Things are not smart by themselves; they are smarter than a reference point, with some level of extent. This comes from the fact that we, as humans, are not smart enough to understand how to map the effects of smartness to their atomic causes. Despite the current knowledge on the brain and its functioning we cannot accurately measure nor quantify smartness. We cannot even say with certainty if it is static, if we are born with smartness potential, or if it is stimulated through our daily living. But society has been eager to label smartness, and so that it did, by setting a relative scale.

In fact, considering smart as a human construction, the first paragraph of this chapter deserves a correction – Things started to become "smart" with the appearance of the smart-ape, also known as human. Humans are distinguished by their ability to develop and use technology, a collection of physical and mental artefacts, to aid their cognition and specialization in certain tasks. The idea that a sharped rock could be attached to one end of a stick led to one of humanity's first physical artefacts – A spear, designed for hunting and fishing. We can think of language, arithmetic and logic as examples of mental artefacts as they rely on information rules and structures instead of physical properties but are nonetheless human developed basic tools.

So these artefacts defined us, humans, as smart. The more artefacts that a human would hold the smarter it would be considered as. But, as it was emphasized at the beginning of this chapter, these artefacts seem to be following their own quest for smartness today, and with it their collection, and consequently the human evolution, may then be left with a secondary priority level. Although the contribute of technology to the human development during the last decades seems unquestionable, the excess of automatized processes that are no longer intended to free the human from methodical tasks but are just fulfilling its developed contemporary need for laziness may lead to a turning point. It is also unquestionable that the smart-phone has had an important role on the way we connect today, but it is also known for getting us closer from those far away but farthest from those close, and for making us use time mindlessly anywhere, anytime. This trend, which focuses on the development of technological features for its own showcase, disregarding the impact on sociologic aspects, is defined as technology-centred evolution. This is opposed to a human-centred evolution in which the human is kept in the loop, its quest for personal enhancement is not forgotten and the technology is designed to fit and smarten the human and elevate its lifestyle. This work would be focused in the latter, grounded by data that supports that human smartening, or behavioural improvement, has a more permanent impact on the desired outcome then its masking through controlling smart-technology.

An important underlying milestone of this study would be the understanding of the best practices that lead to a human-centred approach. To achieve this goal it would be crucial to understand how can the human be motivated to use new tools to improve its efficiency on daily tasks, or even to develop new expertise – to be smarter. And with that would come the understanding that these motivations are divided between two basic kinds.

People find motivations to everyday, demanding or tedious tasks in very different ways, but these can be thoroughly packed within *transactional* and *emotional* levels. The first is related to the carrot principle, as the motivation relies in a prize awarded by successfully completing a task. This award is often tangible, but not necessarily. Motivations in this level are called *extrinsic* motivations. The emotional engagement goes a lot beyond these rational rewards. It is related to ones willing to achieve something greater than itself and to a psychological contract with the task. Motivations in this level are called *intrinsic* motivations. Each interaction between two entities results of a combination of the two levels of engagement – Transactional and emotional – presented before. Some are more transactional and others more emotional, by nature. But they are rarely completely dissociated.

For the last few years this author developed the habit of playing basketball every Sunday morning at a beautiful set in Lisbon called Monsanto. It started with a group of close friends that got together there. But as weeks passed on, some motivational phenomena started to show. It became evident that each one of us had very different levels of transactional and emotional engagement towards this routine. Most were under a majorly transactional engagement. For them there were rational achievements behind playing the game, as for example weight loss. But with the time passing these extrinsic motivations started to wear off, and only those with a greater emotional attachment to the game kept the habit of showing up every Sunday morning. I personally do not expect to earn more from it than the simple fun of playing the game, of improving my game, of socializing with my friends and share the feeling. Me and my friend Sofia were the mostly emotionally attached ones, and we still play basketball every weekend. Nevertheless, during cloudy mornings sometimes I feel the need of adding an extra extrinsic motivation to Sofia in order to make her risk the chances of getting rain. I often promise her a cookie at a nearby place.

What was learnt from this experience is that the two kinds of motivation often coexist, but that extrinsic tend to sparse quickly over time while intrinsic bring a much more permanent drive.

This work immersed into two of the trendiest smart-artefacts among the engineering community - The smart-city and, by inheritance, the smart-home - to review them under the human-centred approach. Again, comprehending the groundwork behind the buzzword seemed relevant. This would be the understanding of what a smart-city should be. To accomplish this a look back into pre-historical times would again be needed, back to when communities started to develop.

As the human developed the artefacts that made it smart a specialization phenomena also started to occur. Each developed artefact would bring a special skill to the individual who hold it. So as creativity made this collection of artefacts to disperse, a considerable amount of differently skilled individuals developed. The human was then smart enough to understand that combining different specializations from a group of individuals could generate a greater value to the group. And with this the first communities became.

*Community* is then defined as an aggregation of entities that share services between them to reach common or individual goals.

For the matter of this study cities are no more than a collection of complex communities. So this must lead to the understanding of what a smart-city should be, a city with enhanced and empowered communities, each characterized by intricate composite specializations, brought by a larger amount of participant entities in each of them, that would grow the communities', and consequently the city's, shared services in number, efficiency and resource-usage.

In this work one of these communities was targeted, which was meant to turn smarter – The energy community. This community is traditionally composed by the energy production entities, the energy distribution entities and the energy consumers. The first challenge would be to understand how could the relationships between these entities be strengthened. The next would be to understand which other entities or communities could collaborate with it in order to enhance its generated value. According to the definition of smart-city introduced previously, accomplishing these challenges would mean contributing to smarten this community and, by inheritance, the city it belongs to.

It was considered as fundamental to have a broad understanding of how the relationships between these entities were established at the time of this work. It came as a conclusion that the engagement made between these entities was majorly set at a transactional level, and neglecting the merits that intrinsic motivations could bring to bond the several entities of this community together and to develop innovative services, to be consumed internally between them or externally from collaboration. By acknowledging this, using this kind of engagement was considered as a very important step to achieve the smartening of the energy community as described before, and soon became the first milestone for this work.

In a consumer perspective energy has traditionally been seen as a simple commodity that the consumer demands to have unquestionably available at home, in every time of need. There is not much a sense of quality associated to this service. Because of that evolving the consumer/provider relationship would need to go beyond evolving this basic service.

A persuasive extrinsic motivation for consumers to collaborate with the providers is their own energy savings potential. It became clear that an efficient way to engage the consumer would be through innovative services that might appeal to these savings. And although it may be unsuspected, the energy provider companies are often aligned to achieve this goal. Besides the marketing revenue coming from having the costumers acknowledging that the provider is maximizing their savings there is also a consequence in operational costs reduction of the provider's service, related to consumption peaks and grid management, as it gets to collect data to learn from its customers consumption patterns. But for these two entities to take value from the collaboration, to set this alignment between the customers' demands and the provider's interests, a large set of the customers would have to be engaged with the electric and be providing data to it. This wouldn't be possible with scattered, non-integrated solutions.

Today this effort is being done through smart-power-plugs, which was considered as a technology-centred solution in the sense that it misses some premises about the human lifestyle and condition that were thought to be relevant. These plugs allow the user to monitor the electric consumption of the appliances to which they are connected. But this strategy was considered to be failing due to its inability to grant its own democratization, brought by three factors – Price, comprehensibility and consequentiality. These solutions' price tag tends to range between values that target high-end classes of developed countries, which are commonly niche markets. The initial investment required by these products, and the slow cash-back promised, is inevitably leading this cash-back focused solution to a weak distribution. This also leads to a non-prolific harvesting of data and, with it, a new link inside the energy community, between the consumers and providers, is lost, as it is the opportunity for the electric utility companies to tune the energy distribution and its generic operation for better efficiency. At the same time, these solutions miss the fact that many users are not sufficiently educated nor have the time to process the information that they are being given - The appliances' electric consumption readings, which are considered as of low comprehensibility. And even for those users whom understand these readings and are able to conclude about the appliances' consumption, often there is not a consequentiality to follow since the main outcome that this information could lead to would be the purchase of a new, less energy-greedy appliance, an investment that the consumer is not often willing to do, nor that pays itself in a short term to justify the investment. Also, the motivation is solely in a transactional level, leaving out an emotional contract with the task, which is considered to be leading to an inevitable put away of the device after the frustration of the lack of results settles in, in most cases.

– *Pedro Ferreira, author*

**Motivation**

This work presents an alternative view towards the residential energy efficiency promoting technology – A human-centred approach. It is proposed the use of technology to monitor the user's daily life behaviours that have an impact on the energy efficiency of several appliances, instead of monitoring their consumption. This behavioural data is empirical, meaning that it is easily understandable by the user since it results of direct consequences of its actions. Also it consists of information that the user can use at any time to improve or maintain its best practices, and because of that the consequences of the use of this technology are considered as more immediate than those that may come from the smart-power-plug's technology. This approach keeps the user in the loop and empowers it with the decision making, to be supported by technology, instead of the opposite. The user's continuous effort to improve and its contract with its past improvements should make the technology to not be forgotten over a short term, and this would be accomplished without an excessive intrusion, as the technology is understanding and adapting to the user's lifestyle and counselling behavioural changes at the pace of the user.

The focus on human behaviour monitoring also brings another set of advantages to the energy community, explicitly related to the harvesting of this kind of data, as it allows perceiving consumption patterns a lot more clearly. This behavioural data can not only be used to split energy use between a discrete number of fuzzy domestic activities, such as cooking, entertainment or rushing out to work, but also deconstruct this into the understanding of the patterns related to each activity and the number of people involved in each one – which was considered as very valuable information for electric utility companies as a way to predict energy use and with that fine tune the energy production and distribution. As an example, a single behavioural monitoring device in a refrigerator, provided with adequate machine learning tools, could be used to infer about the number of people in the house, the cooking periods and following TV-powered digestion periods.

This piece of human-centred technology under development would consist of two building blocks – A physical device for gathering the user's behavioural information and an online platform to support the interface with it.

The design and development of the device, under a set of constraints, became the first task. A prototype for understanding the refrigerator's consumption impacting behaviours was to be developed. A means of communicating with the user was a critical decision. It relied on using the users' domestic WiFi infrastructure to connect the device to the web, which promptly labelled this project under another trendy buzzword – The Internet of Things (IoT). But other critical decisions were to be made, mainly concerned with one of the IoT's major crossroads – The devices' energy consumption.

Structuring the online platform, from the data storage to the interface's design, would follow as the next goal. But before that there was still the need to effectively define how would the device interact with its user in order to sustain the aimed human-centred approach.

It was already acknowledged the need of energy utility companies to better engage with their costumers, the virtues of appealing to the consumers' emotional level and how this was untapped territory for the energy community. The following challenge would be to find the adequate tools to develop these relationships and to achieve these goals. This work would focus on testing the effects of *gamifying* this effort. *Gamifying* comes from the term *gamification,* which can be described as the act of using rules commonly seen in games to develop an emotional attachment to very dissimilar tasks. Here this concept would be applied to the interface with the behavioural monitoring device. In addition to allowing the user to keep up with its behavioural data and to bring real time awareness to it, this interaction with the device should engage the user through intrinsic motivations relying on self and communitarian competitiveness and extrinsic motivations as the reward of achievements.

The game would be played at a physical domain, characterized by the continuous attempt to improve the impacting behaviours on the user's domestic energy consumption, but it would also bring a virtual extension to it in which some strategic game playing decisions were to be made.

Smaller communities of users, as friends and family, were to be incentivised to be brought together on this platform, as these were considered to bring a greater trust to the users regarding the behavioural data sharing and its comparison. The fact that some energy efficiency behaviours are dependent on lifestyle and household composition makes the comparison between users to be considerably more trustworthy when the users know each other and their habits.

The game design should follow the focus on intrinsic motivations, which merits were already presented before, but extrinsic ones still had to have their part on this implementation.

EDP, the Portuguese utility company with the larger share on the residential energy distribution sector, understood that collaborating with the retail community could generate a greater value for the resulting composed energy community, and brought together a set of retail partners to bring discounts to its consumers. They were extending their energy community. But again, a singly extrinsic motivation was being applied to engage the customer. This project proposes to bring retail partners to participate in a reward system of the game being designed, so as the users accomplish their objectives they may get rewarded with offers of their choice. With that, an emotional value is attached to the retail partners' offers, leading to their effective promotion, while the game itself gets strong extrinsic motivations to join the intrinsic that it brought by its gaming nature.

But gamification should go beyond awarding badges or physical rewards and stratifying users through levels or rankings, it should not be considered as a standardized solution that is ready to turn any tedious task into a much more impacting and motivating one by simple application. On the contrary, it was known that a thoughtless gamification application could even lead to deteriorate the relationship with the gamified subject. An important objective of this work would be the study and design of a gamification implementation, which should be later validated empirically with the goal of determining if it could become a valuable asset for engaging the energy consumers on an emotional level, be impacting on their behavioural change and, if so, how.

To validate all these assumptions, from the theory supporting it to the actual implementation of the previously described human-centred solution for residential energy efficiency improving, a pilot experiment would be prepared, and preliminary results presented. The selected households would receive a device built under a set of constraints to fit the human-centred approach described before that would be ready to monitor and to counsel about the energy efficiency impacting behaviours towards a refrigerator. This device would be called EGGY.

Together with the device, a web-app and two web-based mobile apps – for the Android and iOS operating systems, were developed. These would be intended to give the device an interface that would allow the user to keep up with the changes on its behaviour over time, and to gamify the effort of improving these energy efficiency related behaviours.

To conclude, this work aimed to follow a human-centred approach to develop a piece of technology for improving the residential energy consumption, and to validate that approach by harvesting data related to the impact on the behavioural improvement and also to the engagement of the solution over the period of a pilot experiment. This approach consisted on the development of a monitoring device for the energy consumption impacting behaviours and a supporting online platform. This platform would aim to bring an emotional engagement to the task by effectively gamifying the user's interaction with the device.

### Objectives

The objectives of this work would be linked to the understanding of the current scenario of Energy Management (EM) systems and their development, with the design and implementation of a solution for improving an EM system with behavioural data monitoring and a focus on the customers' intrinsic motivations, and with the presentation and analysis of preliminary data from a pilot test of the developed technology.

1. Review and understand the domestic energy distribution and consumption scenario;
2. Review the state-of-the-art regarding Energy Management systems and the current constraints upon their implementation;
3. Review and discuss the prospective role of the intrinsic motivations towards households energy efficiency improving;
4. Implementation of a sustainable low-cost device for gathering and wirelessly communicate domestic energy efficiency related behavioural data;
5. Implementation of a gamified User Interface (UI) for engaging the householders towards their domestic energy efficiency, using harvested data about their behaviours in this setting;
6. Data analysis regarding refrigerator usage behaviours, residential energy efficiency related knowledge and the UI engagement;

### Document Structure

On Chapter 1 the motivation and groundwork of this dissertation is introduced. The basic concepts behind the study in this work are presented and discussed.

On Chapter 2 a literature review over some major topics of this research is presented. This review is divided between three main topics. The first contains information to ground the residential energy consumption patterns and its need for efficiency, which is shown and commented. The second topic focuses on the impact of behavioural change on energy efficiency. The last topic regards the potential role of gamification on behavioural change.

On Chapter 3 the solution developed, an egg shaped device named EGGY and the online platform to support it named EGGY Yolk, is presented. The device is dissected and its operation algorithm described. The contingencies behind its operation mode and the options made are justified. The gamification structure, as the user interface, is also presented and discussed.

On Chapter 4 the objectives and the results of a preliminary pilot conducted with 12 units of the developed prototype of the EGGY technology are presented. Data regarding refrigerators usage and engagement indicators towards energy efficiency improvement is shown.

Chapter 5 concludes this work with a final wrap up of the results, divided between conclusions taken from the literature review, the implementation (both the hardware and software) and the preliminary results of the pilot conducted, and with a suggestion for the consequent future work, which considers the evolution of the technology and also the further validation that should be followed.

2

# Literature Review

## 2.1 Residential Consumption & Efficiency

The residential energy consumption is known to be dependent on climate, the building properties and structure, family size, appliance ownership, and human behaviour and lifestyle in general [1-6]. The dependence on climate immediately acknowledges that one of the main contributors to the residential energy consumption is the room and water temperature control, justified by these processes' high energy spending and generic inefficiency, but also by the impact that these can have into the occupants' comfort and how it is considered as a necessary commodity in harsher climates. Table 1 lists the share of the residential consumption versus the total energy consumption in a set of regions considered to have considerably disparate climate conditions.

**Table 1** **The share of residential energy consumption versus the total consumption per country [7-15].**

| Regions | Share of residential energy consumption versus the total energy consumption | Approximated yearly average temperature |
|---|---|---|
| **Denmark** | 28.5% [14] (2008) | ~7.7°C |
| **Germany** | 25.2% [15] (2011) | ~9.5°C |
| **United Kingdom** | 27.0% [7] (2008) | ~9.5°C |
| **Spain** | 16.4% [12] (2008) | ~14.5°C |
| **Portugal** | 17.7% [11] (2010) | ~15°C |
| **Brazil** | 15.0% [13] (1996) | ~24°C |
| **EU** | 29.0% [8] (2001) | - |

This data leads to conclude that regions with harsher climate conditions tend to have a larger share of their total energy consumption dedicated to the residential sector, but as this result may also come from these regions dissimilar Gross National Product (GNP) and social-economic statuses in general, resulting in variations at the transportation and industrial shares of the total national consumption, as also at the households' energy usage purposes, further analysis must rely on data regarding the shares of the several purposes for energy consumption per dwelling, in each region. Figure 1 shows the energy consumption, measured in tone of oil equivalent (Toe), per dwelling and divided between four types of energy consumption purposes, for the several countries of the European Union (EU-27) and EU-27's own average [8].

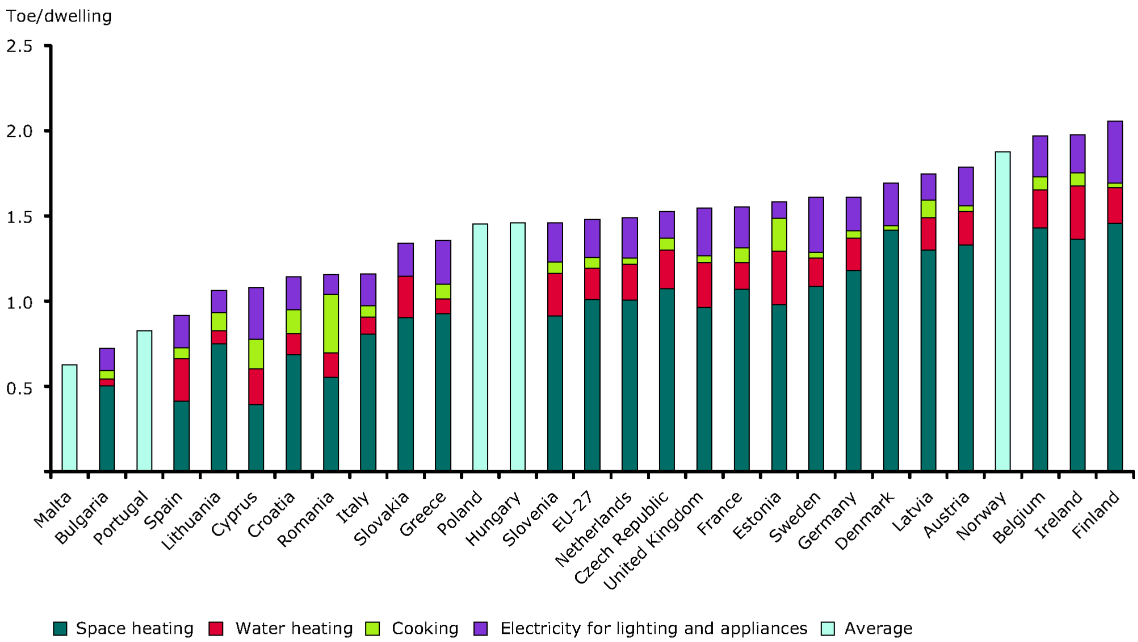


**Figure 1** **Consumption per dwelling in the several EU countries and the EU average (2012) [8].**

It is concluded that households in countries that experience lower temperatures tend to dedicate considerably more of their total energy consumption to room and water heating, but the question remains about how much can this be justified solely by the climate conditions themselves, and not by the average building standards and the occupants income, lifestyle or behaviour. The variations of the consumption distribution among the several countries with similar climate conditions point to the fact that the former do take a role in these results.

It would also be relevant to divide the further analysis between two main categories of energy consumption, set by their type – Heating and cooking, and electricity for lighting and appliances.

A study conducted in the Netherlands, a country that according to the data presented above closely resembles the EU-27 average, documents that building characteristics account for 42% of the variation in energy use for water and room heating, leaving 53.8% of its justification for user behaviour, while only 4.2% is addressed to the occupants' characteristics [16-17].

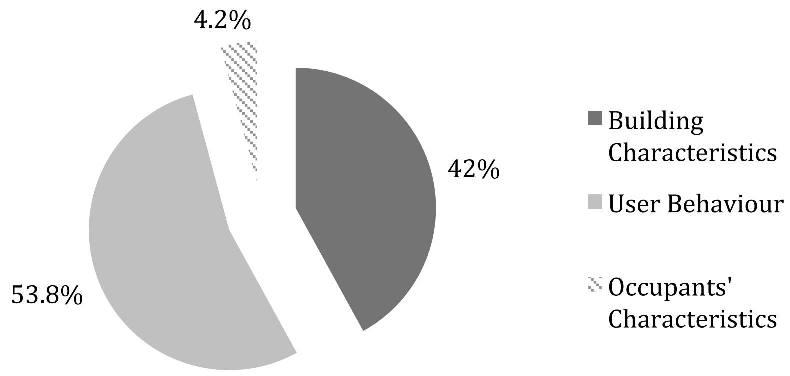


**Figure 2** The impact of user behaviour on the variation of energy use for water and room heating [16-17].

Some studies extend this analysis and include information about several types of heating control systems, as programmable thermostats, manual thermostats or manual valves, and conclude that the households with programmable thermostats have the radiators turned on for more hours than the others [18] and do not keep the lower temperatures considered to be in the comfort range [19], which would lead to a more intensive energy consumption. Another study also considers the impact of the rebound effect – The increase of energy consumption caused by consumer's acknowledgment of past, present or prospective short-term benefits from energy savings. A review of empirical estimates of the rebound effect within the residential sector concludes that the rebound effect of a household's energy consumption destined for heating is approximately 20% [20], meaning that 20% of the efficiency earned through technical improvements of building and appliances is turned into increased consumption, following from direct change in human behaviour towards over-improving its comfort level. Two forms of the same justification are given for this rebound effect, on an economical and societal sense. The first, considerably conscious, states that the consumer increases its consumption because it can afford it, after guaranteeing the savings. The latter, less conscious, relates to the fact that after investing in energy saving technology the consumer may feel that it can loose its self-control over energy spending, leading to deteriorate its behaviour and consequently increase the energy consumption.

Regarding electricity consumption for lighting and appliances, a data analysis on the Danish national statistics lead to suggest that this is more dependent on user practices than on the appliances' energy efficiency, specially if the number of appliances is counted as part of the user practice [16]. This study states that 30% to 40% of increase in electricity consumption efficiency has been gained in the last 30 years in Denmark, but the number of appliances per household has risen for an even larger amount in the same period. The Danish study concludes with the statement that "To realise substantial energy reductions, which is an important part of a future renewable energy system, we need consumers who choose efficient technologies, reduce the number of appliances and think about how they use them." [16]. As this current work would focus in the latter, and the understanding of the best triggers for motivating the consumer to think and to learn about how it uses its appliances at home would become a goal, further relevance was given to studies about the bringing of awareness to the behavioural change towards energy efficiency.

Abrahamse et al. [21] defines two levels of intervention to reach the desired development of behaviour towards the improvement of appliances usage and consequently their energy saving. According to this author, behavioural interventions may be aimed at voluntary behaviour change by targeting a consumer's perceptions, preferences and abilities, or they may be focused on changing the context in which decisions are made – For example changing financial rewards, laws or the provisioning of energy-efficient equipment, as a way to improve the pay-off and make the energy-saving activities to be more attractive. This study also divides the behaviour into two categories, namely efficiency behaviours and curtailment behaviours. The first are described as one-shot and entail the purchase of new, more energy-efficient equipment, while the second is related to continuous effort to reduce the energy use of the installed technology.

Abrahamse et al. [21] further analyses how do several types of (a-priori and a-posteriori) interventions impact on behaviour change towards domestic energy efficiency. Commitment, goal setting, information, and modelling are defined as a-priori interventions, while several levels of feedback and rewards are defined as a-posteriori interventions.

Regarding a-priori interventions, this study concludes that, in view of the long-term effects found in several studies, commitment may lead to a successful reduction of energy use. It also states that goal setting is more effective when combined with feedback. Regarding information it is concluded that the success largely depends on its specificity, and that a personalized approach such as tailoring may turn to be more effective. Finally, modelling – which entails the provisioning of recommended behaviours – was acknowledged as impactful in knowledge increase and was also considered to be effective in reducing the energy use. So this kind of intervention reveals to be effective in the development of the previously described curtailment behaviours [21].

When concerning a-posteriori interventions this study also concludes that the more frequent a feedback is given the more effective it is, and that, between environmental and monetary, it was unclear whether it would make a difference the kind of information use in the feedback for its effectiveness – behavioural was not considered in this study. It is also stated that combining comparative feedback with rewards in a contest setting proved to be successful, and that although rewards seem to have a positive effect on energy savings in general several studies point to the fact that this is rather short-lived.

Although these interventions proved to be effective towards the goal of improving the domestic energy savings, it would be important to assess whether such interventions are socially efficient, through a cost-benefit analysis, prior to their implementation [22]. Clinch et al. presents a template for this analysis but considers as one of its weaknesses the assumptions needed to be made regarding household behaviour (e.g. about how will individuals react once energy efficient measures have been installed in their houses). As so, the result of this study turns to be inconclusive when a cost-benefit analysis of interventions on efficiency and curtailment behaviours is intended.

The a-priori recognition of habitual behaviour, as routines, and the ability to consequently tailor these interventions would also be critical for their impact on domestic energy savings to be increased [23]. Joana M. Abreu et al. concludes that from electricity readings it is possible to automatically and anonymity extract and group persistent routine patterns in households, and that this information is useful to help design better incentives for load shaping and the development of new services, tailored to specific populations. It is also concluded that it is possible to cluster together groups of days that have similar baselines in common, as days of no-occupancy, cold weekend days, cold working days and temperate days.

Carroll et al. divides the implementation of the previously presented interventions into three main categories [26]:

1. In-home devices and displays providing real-time feedback;
2. Customized, regular feedback handled to customers;
3. Dynamic pricing and rate design programs, typically involving smart-meter technology;

This research suggests that the first may generate electricity savings of 5% to 15%, on average and that the second may motivate residents to lower energy use from 0% to 10%, while the third is considered to be out of the scope of the study due to its requirements of infrastructure investment. This study concludes with the presentation of three behavioural change program models for consideration to utility managers, as presented on Table 2.

**Table 2** **Three suggestions of behavioural change program models and their characteristics [26].**

| | **Model 1**<br>**In-Home Energy Use Monitor** | **Model 2**<br>**Indirect/Comparative Feedback on Home Energy Use** | **Model 3**<br>**Hybrid Approach – Direct and Comparative Feedback** |
|---|---|---|---|
| **Program Basics** | Participants receive a monitor that provides real-time feedback on home energy use in order to track and experiment with their energy use behaviour; | Participants receive regular reports in the mail that will compare their energy use with neighbours in similar homes. Targeted energy saving tips will also be communicated; | Participants receive regular comparative feedback reports and energy tips. Participants will be encouraged to make use of real-time power monitors that can be purchased or borrowed for several months at a time; |
| **Customer Engagement Method** | Opt-in | Opt-out | Opt-in<br>(In-Home Device)<br>Opt-out<br>(Reports) |
| **Targeted Participant Household Savings (as % of kWh)** | 5% (3% to 7% range)<br>Valid among self-selected participant population; | 2% Average on the total customer population;<br>5% to 10% range on targeted segments; | 2%+ Average on the total customer population;<br>5% to 10% range on targeted segments; |
| **Main Advantage** | Real-time feedback for participants | Cost effective approach with broader reach | Hybrid approach maximizes savings potential |
| **Main Disadvantage** | Significantly higher cost per kWh saved | Requires integration with system data | Greater complexity / resource requirements |

It would then arise the question of how could the user be motivated to improve these behaviours, and if smart metering technology is capable of supporting the types of relationship and practice that are likely to lead to lower-impact energy use [45]. Darby et al. starts this analysis by introducing the definition of *affordances*. "The idea of affordances was introduced by the psychologist J. J. Gibson to convey the possibilities for action in one's surroundings [46]. Affordances were defined as the 'action possibilities' latent in the environment". Darby exemplifies this with the idea of a ball of wool and how this can present different affordances to a cat, child or adult. The idea of affordances provides a useful way of contemplating possible interactions between householders and their artefacts in future, "smarter" homes [45]. Darby et al. stresses out that in spite of the references to personal needs and choice (affordances), most are presented essentially from the point of view of the controller of the electricity grid, as the main offer to the householder appears to be automation of some functions and the prospect of some form of time-varying electricity pricing, plus a degree of remote control via the Internet, a sort of control that could be attractive to a segment of the population, but that it could alienate others and that has not, to date, shown any substantial evidence of reducing demand. According to Strenger et al., taking control away from the customer cannot be relied upon to improve the situation, as it may actually entrench and legitimize high-demand practices, disengaging customers from any need to consider and question them – leading to the previously presented, and commonly referred within the literature, rebound-effect.

Darby et al. states that besides the environmental impact, affordances towards 'smart' technology can offer other benefits to the energy system. Owen et al. identified a list of outcomes as motivations for the introduction of smart metering technology: "reduced fraud and theft; elimination of the cost of employing meter readers and the inconvenience to some customers of waiting for them to call; an end to the stigma and additional cost attached to prepayment; reductions in peak demand and avoided investment in new capacity; a lower environmental impact from avoiding an inefficient or high-carbon marginal generating plant; and improvements in the efficiency of the market" [46, 48]. But regarding the achievement of these goals, Darby concludes that the theory of affordances points to the fact that much of the significance of socio-technical innovation, as it is the smart metering, can be described in relational terms – in terms of how people and things interact with other people and things, and to what ends. And that it should involve a great deal more than automation and fine control.

## 2.2 The Refrigerator Case

Refrigerator-freezers are commonly considered as an essential appliance, which has lead to their broad distribution among households. This, combined with the fact that these are characterized by a continuous consumption of energy throughout a day, has turned them into a common target for energy efficiency efforts. A big part of this effort has been done through introducing energy efficiency standards to encourage consumers to use more efficient units [28]. The energy efficiency standards will, eventually, eliminate the least efficient products from the market, and further relevance will have to be given to the understanding the energy consumption behaviour of these devices and to the impact of the user behaviour and environmental setting on it [28]. But as these appliances renovation cycle is long, due to its monetary and handling costs, it is already becoming evident that tackling the energy consumption of the implemented units may lead to better short-term results.

Figure 3 shows the absolute (1) and relative (2) annually consumption of the domestic large electrical appliances for the years of 2011 and 2012. The decrease in the consumption of refrigerators and freezes is explained by the substantial electricity savings achieved with the diffusion of newly, more efficient equipment [33].

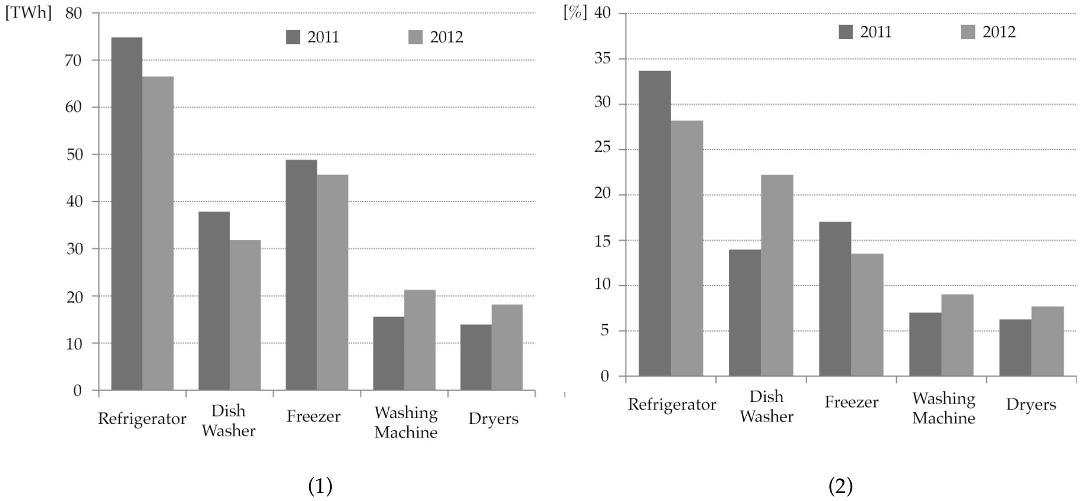


**Figure 3** **Consumption of large electrical appliances by type (EU-27) [33].**

Figure 4 shows the evolution of the market share of efficient refrigerators. It is shown that by 2012 almost the total amount of refrigerators in EU-15 was labelled A or above, but that only 15% were under the two top categories. By crossing Figure 3 with Figure 4, and ignoring other impacting interventions of refrigerators' energy savings that are not related with the units' renovation, it can be roughly considered that a decrease of 19% on A labelled refrigerators and the increase of 14% on A+, of 4% on A++ and 1% on A+++ lead to close to 10 TWh of electricity saving.

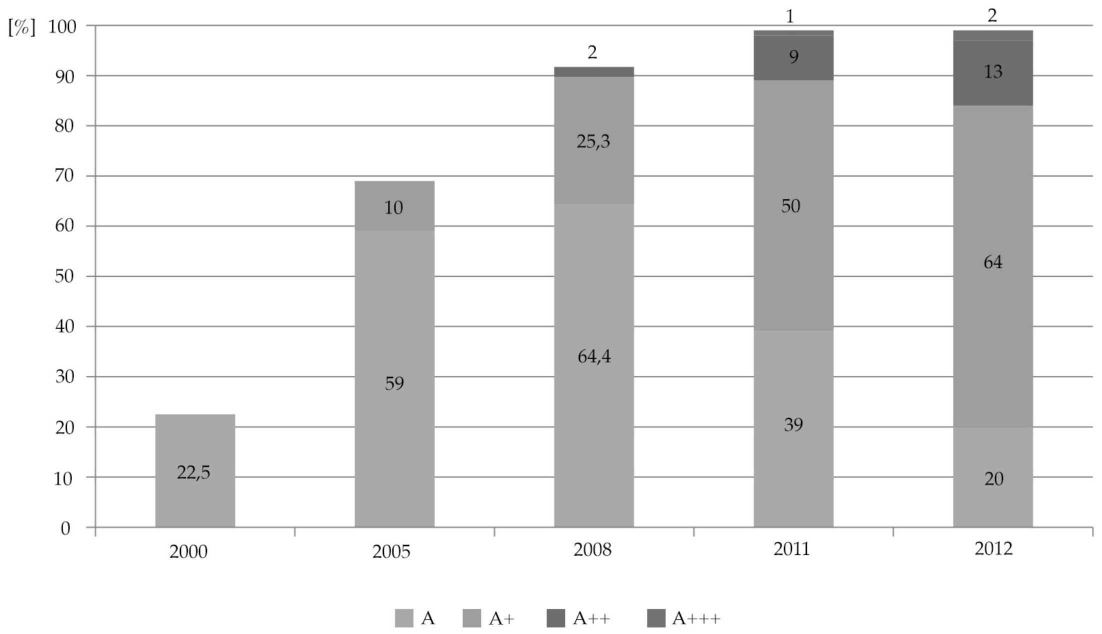


**Figure 4** **Market share of label A, A+, A++ and A+++ for refrigerators (EU-15) [33].**

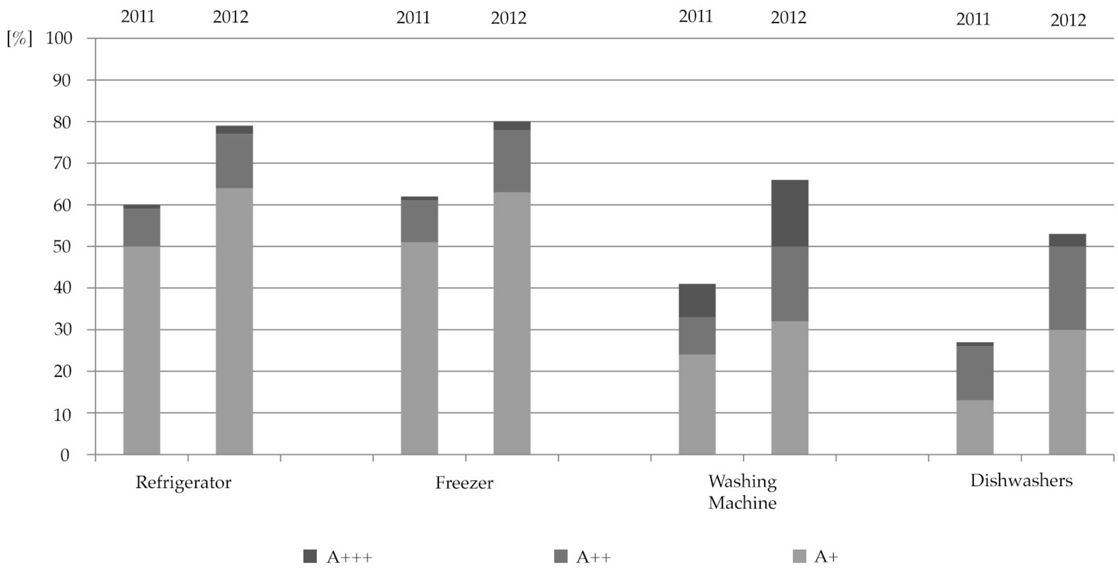


**Figure 5** **Market share of efficient (labels A+ and above) new appliances (EU-15) [33].**

Figure 5 shows data regarding the market share of efficient new appliances (rated A+ or above). The washing machine is the large appliance that shows a bigger improvement on the market shares of A++ and A+++ labelled units between these two years. The author gives no justification to this fact, but it may be related to an additional effort from the washing machines' manufacturers to promote the highly efficient units, either for marketing or production and distribution constraint reasons, to the consumers' acknowledgment of a faster cash-back of these units or to the consumers' appreciation of additional features that may come along with the increased energy efficiency of these units.

R. Saidur et al studied the impact of behaviour in a refrigerator's electricity consumption. This study divides this impact between the effect of room temperature, thermostat setting and door openings, and it relies on experiments with one single free variable (fixing the remaining) over two household refrigerators. The technical specifications of these refrigerators, named Model E and Model S, are shown in Table 3.

**Table 3 The technical specifications of two models of refrigerators used in a study to determine the impact of user behaviour on their energy consumption [28].**

| Specifications | Model E | Model S |
|---|---|---|
| **Freezer Capacity (l)** | 80 | 80 |
| **Fresh Food Compartment Capacity (l)** | 220 | 220 |
| **Power Rating (W)** | 160 | 160 |
| **Current Rating (A)** | 0.9 | 0.9 |
| **Voltage (V)** | 220 | 220 |
| **Frequency (Hz)** | 50 | 50 |
| **Defrost System** | Auto Defrost | Auto Defrost |
| **Number of Doors** | 2 | 2 |

Regarding room temperature, this study starts by stating that about 60% to 70% of a refrigerator's load comes by conduction through the cabinet walls, which is proportional to the difference between the ambient temperature and the internal compartment temperature. The higher the difference, the higher is the load imposed to the refrigerator. Another reason that justifies the impact of room temperature on a refrigerator's energy consumption is the fact that its compressor's efficiency also declines as the ambient temperature rises. This experiment's data, shown in Figure 6, determines that for every increase of 1°C on the room temperature the energy consumption of the Model E and Model S refrigerators rises on average 47Wh and 53Wh, respectively. The author confronts this result with that obtained by Meier et al. in a study conducted in the year of 1993, in which an average of 120Wh per 1°C increase in the room temperature was determined. The author justifies this with the poor energy efficiency of the refrigerators existent in that period, and with the fact that its study was conducted with the latest models available in the market.

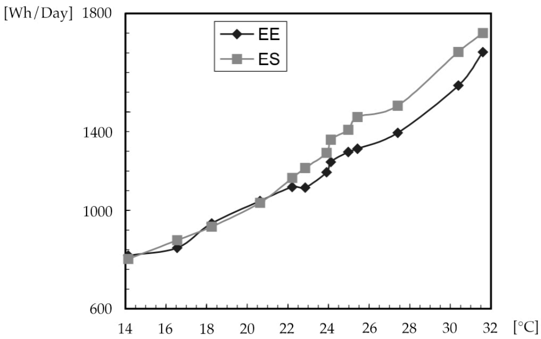


**Figure 6** **Variation of daily consumption of two refrigerators with room temperature [28].**

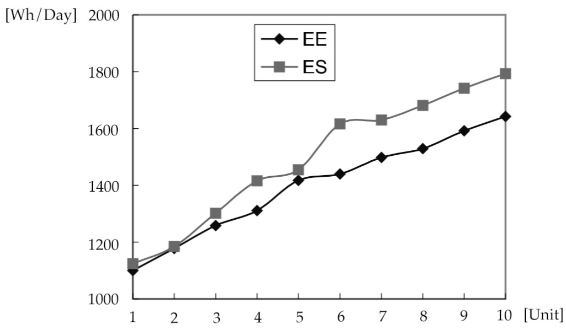


**Figure 7** **Variation of daily consumption of two refrigerators with the thermostat setting position [28].**

Regarding the thermostat level, the data analysis presented in this study shows that energy consumption increases about 7.8% for each degree reduction in the compartment temperature. Figure 7 shows this result.

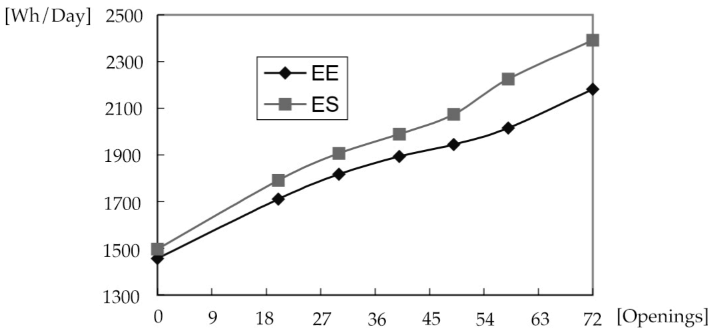


**Figure 8** **Variation of daily consumption of two refrigerators with the door openings [28].**

Setting the adequate temperature of a refrigerator would extend energy efficiency concerns, as epidemiological data from Europe, North America, Australia and New Zealand indicate that a substantial proportion of foodborne disease is attributable to improper food preparation practices in consumers' homes

[37]. Data also shows that a large proportion of refrigerator owners lack knowledge about the adequate refrigeration temperatures.

Godwin et al. suggests that to guarantee the food's adequate conservation the temperature should be maintained at 4.4°C or below [38]. It further conducted a study with 200 homes of the United States in which the temperature of three different locations of the refrigerator's compartments – Top shelf, bottom shelf and door – would be put under scope.

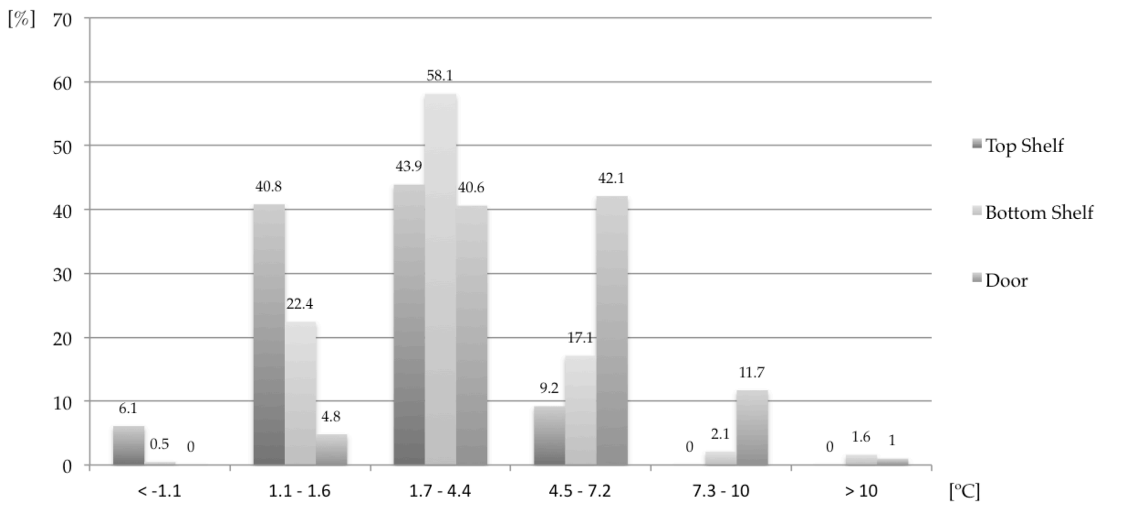


**Figure 9** **Distribution of mean temperatures for three locations in home refrigerators [38].**

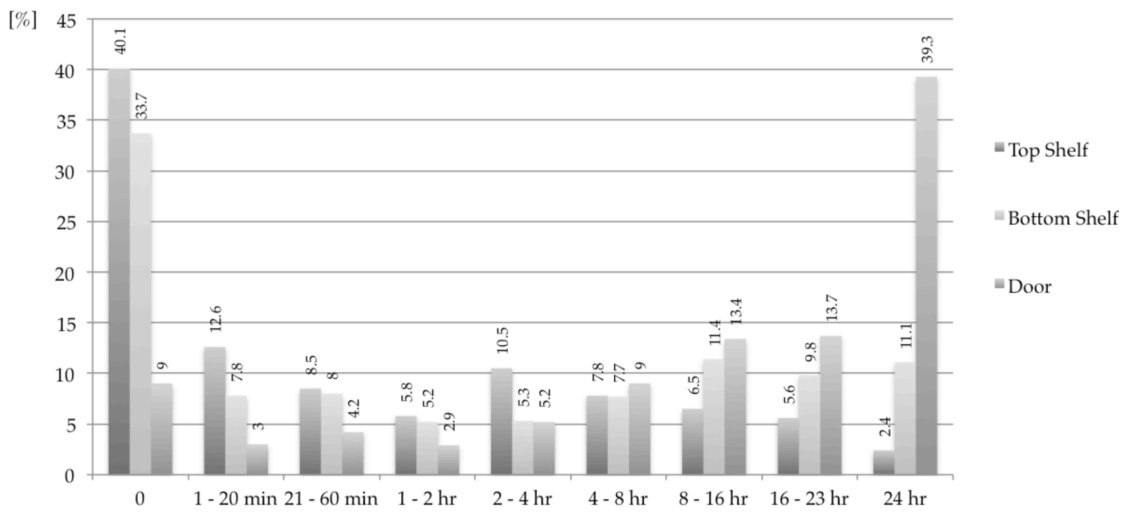


**Figure 10** **Percentage of refrigerator compartments that exceeded 4.4°C for specified lengths of time [38].**

The mean temperatures observed for the top shelf, bottom shelf and door were respectively 1.9°C, 3.3°C and 5.2°C, and 9%, 25% and 61% of these locations areas, respectively, registered average temperatures above 4.4°C. Over 66% of the refrigerators kept the door temperature above 4.4°C for more than eight hours per day. The temperature rose above this level for more than two hours a day in 33%, 45% and 80% of the refrigerators' top shelf, bottom shelf and door, respectively [38].

Laguerre et al. states that as the operating conditions of a domestic refrigerator are subject to random variation, due to consumer practices as thermostat setting, room temperature, loading, and others, the compartment's temperature predictions should be carried out by stochastic models instead of the commonly used deterministic models which assume that the coefficients, and initial and operating conditions, are accurately known. This study would have as goal to determine the influence of two random variables, the room temperature and the thermostat setting, on the air and load temperature on a loaded domestic refrigerator. A simplified model of a refrigerator is presented, to enable calculation of the air temperature at the top/bottom and near the cold/warm walls ($T_{act}$, $T_{acb}$, $T_{awt}$, $T_{awb}$) as a function of room temperature ($T_e$) and the air temperature near the thermostat ($T_{th}$). It also makes it possible to calculate the load temperature at the top ($T_{st}$) and at the bottom ($T_{sb}$) [36].

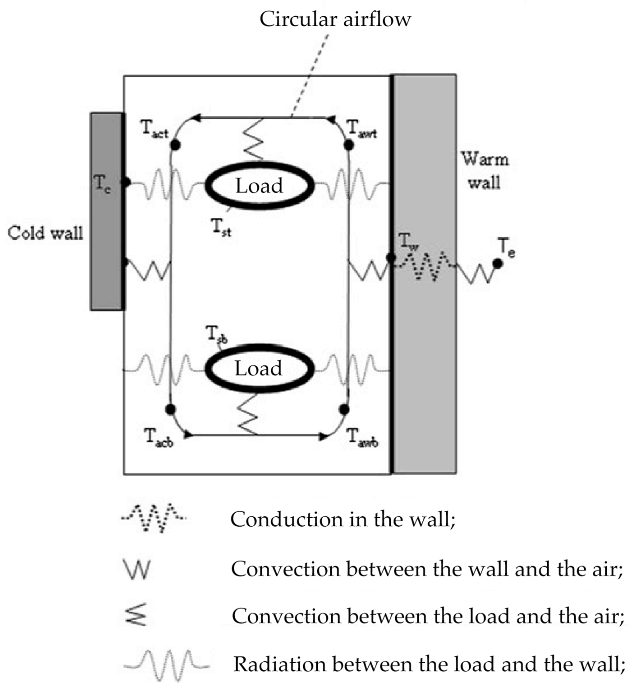


**Figure 11** **Different modes of heat transfer considered in Laguerre's simplified model [36].**

**Table 4** **Nomenclature used in Laguerre's simplified model [36].**

| Nomenclature | | | |
|---|---|---|---|
| $A_c$ | Surface of evaporator (cold wall) contributing to convective heat transfer ($m^2$) | $\lambda$ | Thermal conductivity ($W\ m^{-1}\ K^{-1}$) |
| $A_w$ | Surface of warm wall contributing to convective heat transfer ($m^2$) | $\beta$ | Thermal expansion coefficient ($K^{-1}$) |
| $A_r$ | Wall surface contributing to heat exchange by radiation ($m^2$) | $\rho$ | Density ($Kg\ m^3$) |
| $A_e$ | External surface contributing to convective heat transfer with the environment ($m^2$) | $\nu$ | Kinematic viscosity ($m^2\ s^{-1}$) |
| $C_p$ | Air heat capacity ($J\ Kg^{-1}\ K^{-1}$) | $\alpha_c$ | Dimensionless convective heat transfer between the air and the cold wall $= e^{-\beta_c}$, $\beta_c = h_c A_c/\dot{m}C_p$ |
| $g$ | Acceleration due to gravity $= 9{,}81\ m\ s^{-2}$ | $\alpha_w$ | Dimensionless convective heat transfer between the air and the warm wall $= e^{-\beta_w}$, $\beta_w = h_w A_w/\dot{m}C_p$ |
| $h$ | Heat transfer coefficient ($W\ m^{-2}\ K^{-1}$) | $\alpha_s$ | Dimensionless convective heat transfer between air and load $= e^{-\beta_s}$, $\beta_s = h_s A_s/\dot{m}C_p$ |
| $\dot{m}$ | Mass flow rate of the air in refrigerator ($Kg\ s^{-1}$) | $\beta_e$ | Dimensionless conductive and convective heat transfer between the warm wall and the environment $= h_e A_e/\dot{m}C_p$ |
| $T_{ab}$ | Air temperature at the bottom of the cavity (K) | $\beta_{rct}$ | Dimensionless radioactive heat transfer between the cold wall and the load located at the top of cavity $= h_{rct} A_{rct}/\dot{m}C_p$ |
| $T_{at}$ | Air temperature at the top of the cavity (K) | $\beta_{rcb}$ | Dimensionless radioactive heat transfer between the cold wall and the load located at the bottom of the cavity $= h_{rcb} A_{rcb}/\dot{m}C_p$ |
| $T_{acb}$ | Air temperature at the bottom near the cold wall (K) | $\beta_{rwt}$ | Dimensionless radioactive heat transfer between the warm wall and the load located at the top of cavity $= h_{rwt} A_{rwt}/\dot{m}C_p$ |
| $T_{act}$ | Air temperature at the top, near the cold wall (K) | $\beta_{rwb}$ | Dimensionless radioactive heat transfer between the warm wall and the load located at the bottom of the cavity $= h_{rwb} A_{rwb}/\dot{m}C_p$ |
| $T_{awb}$ | Air temperature at the bottom, near the warm wall (K) | | |
| $T_{awt}$ | Air temperature at the top, near the warm wall (K) | | |
| $T_c$ | Cold wall temperature (K) | | |

...

| Nomenclature | |
|---|---|
| $T_e$ | Room temperature (K) |
| $T_{st}$ | Load temperature at the top of the cavity (K) |
| $T_{sb}$ | Load temperature at the bottom of the cavity (K) |
| $T_{th}$ | Air temperature near the thermostat sensor (K) |
| $T_w$ | Warm wall temperature (K) |

The model suggested by Laguerre et al. would assume that both the temperature near the thermostat ($T_{th}$) and the room temperature are known. The model would then be expressed in the matrix form as,

$$A \cdot X = B \cdot T_e + C \cdot T_h$$

where,

$$A = \begin{bmatrix} \alpha_c - 1 & -\alpha_c & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -\alpha_w & \alpha_w - 1 & 0 & 0 \\ 0 & 1 & -\alpha_s & 0 & 0 & 0 & \alpha_s - 1 \\ 0 & 0 & 0 & 1 & 0 & \alpha_s - 1 & 0 \\ 0 & 0 & -1 & 1 & -(\beta_e + \beta_{rwt} + \beta_{rwb}) & \beta_{rwb} & \beta_{rwt} \\ \beta_{rct} & -1 & 1 & 0 & \beta_{rwt} & 0 & -(\beta_{rct} + \beta_{rwt}) \\ -\beta_{rcb} & 0 & 0 & 1 & -\beta_{rwb} & (\beta_{rwb} + \beta_{rcb}) & 0 \end{bmatrix}$$

$$X = \begin{bmatrix} T_c \\ T_{act} \\ T_{awt} \\ T_{awb} \\ T_w \\ T_{sb} \\ T_{st} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -\beta_e \\ 0 \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} -1 \\ 0 \\ 0 \\ \alpha_s \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

The author further emphasizes that in practice there are more random variables as the amount, type and distribution of loading in the refrigerator and the door opening frequency and duration, but to avoid such complex situation and as a first approach, only room and thermostat temperatures are considered as random parameters, which are assumed to be constant with respect to time [36].

Regarding door openings, Alissi et al. defines four categories of loads associated with it:

1. Convective heat transfer from the warm ambient air flowing across the cooler refrigerator surfaces;
2. Latent heat transfer with condensation of water vapor from the moist air flowing across the cooler refrigerator surfaces;
3. Radiated heat transfer from the surroundings to the interior surfaces;
4. Sensible heat transfer from the warm air mass within the cooled space after the door is closed.

These would justify the observed increase in the energy consumption of 9Wh and 12.4Wh per door opening, with 12 seconds of duration, of the Model E and S, respectively, of Alissi et al. study. The study does not contemplate the effect of other openings' durations in the energy consumption of any of the refrigerators.

Alissi et al. concludes that room temperature has the higher effect on energy consumption, followed by door opening and thermostat setting position.

# 3

# State-of-the-Art

## 3.1 Energy Management Systems

"A smart grid is an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it – Generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety" (as per the definition given by the Expert Group 1 of the EU Commission Task Force for Smart Grids) [42]. In practice, a smart grid is considered to be a modern power grid that supports bidirectional communication between energy providers and consumers for fine-grained metering, control, and feedback, and that has as a key outcome the enhancement of energy efficiency and manageability of available resources. Energy management (EM) systems, often integrated with home automation systems, provide an infrastructure to the consumers to understand, control, and optimize energy consumption. Although EM systems have been around for a couple of decades, several technological factors posed to be an entry barrier that prevented their large-scale adoption. But technological advances such as the disaggregation technique for non-intrusive load monitoring at the appliances' level and the pervasive availability of sensors, which provide more contextual information and thus increase its feedback effectiveness, as the thriving of cloud computing, which allows the consequent analysis and report of information in real-time, are changing this scenario rapidly. The growing popularity of social networks is also said to contribute to the incorporation of comparative and persuasive features into EM systems that motivate behavioural changes in consumers, and consequently to the adoption of this technology [49].

Saima et al. states that "EM systems must provide advanced and versatile functionality while keeping the installation simple and running cost low. The systems should integrate with users' daily activities and offer actionable feedback" [49]. But as stated by Darby et al., most of the 'smart' technology available for domestic use today focuses on the houses' automation and fine control, which due to the specificities of a heterogeneous set of objects under control make this technology to violate the above premise, both in cost and simplicity but also on the absence of actionable feedback, as it imposes its own control.

Saima's study divides the requirements of EM systems into eight main categories – Monitoring, Disaggregation, Availability and Accessibility, Information Integration, Affordability, Control, Security and Privacy and Intelligence and Analytics – and analyses these requirements fulfilment for eight implementations of EM systems suggested by recent literature.

Regarding Monitoring, the authors state the importance of providing information at several temporal granularities, such as 15 minutes, hourly, daily and weekly, backed Fischer's study [58] which noted that feedback is most successful when it is provided frequently and over a long period of time. This added success is justified by Weiss et al. [59] with the fact that consumers can then directly relate near-real-time information with their energy use actions [49].

Consumers tend to have a misperception about the energy consumed by individual appliances [60]. In order for them to be able to use the feedback provided by an EM system it would be important to guarantee that disaggregated information about each of the contributing appliances' energy consumption is delivered. This is commonly done today through the use indirect load sensing methods that provide disaggregated information based on specific current and voltage waveform "signatures" of individual appliances [49].

The Availability and Accessibility requirement is related to how the information is accessible by the consumer. Saima et al. emphasizes that the information should be always available and accessible through an easy-to-use interface. Saima also refers the importance of the remote access, use of push-notification technology, which is granted by web-based interfaces and that enable keeping the user alerted about urgent notifications in real-time.

An EM system should also integrate other types of information besides real-time energy consumption, such as indoor and outdoor climate conditions, presence over time, historical energy consumption data, data regarding similarly profiled households, data about the energy production, availability and transportation, and other that may justify the adequate energy consumption of

**Table 5** **Evaluation of various energy management systems (1/2) [49].**

| | Monitoring | Disaggregation | Availability and Accessibility | Information Integration | (...) |
|---|---|---|---|---|---|
| **PERSON** [50] | Yes | Yes | Monitor and control centre available at user premises; No web or mobile interface; | Aggregates others' usage information; Integrates temp, humidity, luminance, and motion sensor data; | |
| **WattDepot** [51] | Yes | Possible, by separating sensors; | Web-based interface; | Automatic interpolation; | |
| **ViridiScope** [52] | Yes | Yes | Not discussed; | Aggregates magnetic, acoustic, and light info; | |
| **Mobile Feedback** [53] | Yes | Yes | Interactive; readily available feedback on a smartphone; | Integrates historical information; | |
| **DEHEMS** [54] | Yes | Yes | Web-based UI, real-time display unit; | Integrates info from sensors, electric supply and gas supply lines; | |
| **EnergyWiz** [55] | Yes | No | Mobile phone app; | Integrates historical usage, and user info from peers, social network friends, and EnergyWiz users; | |
| **NOBEL** [56] | Yes | Yes | Mobile phone app; | No | |
| **ALIS** [57] | Yes | No | Web, smart-phone, touch-panel, art display; | Integrates historical use, community usage data | |

a household. This data coming from such diverse sources tends to lead to asynchrony – Data with very dissimilar timestamps. To make the integration of this data perceptible to the consumer, interpolation is needed to guarantee that a unique sampling rate is presented to it. This is commonly done today through the use of semantic web technologies [61].

Affordability considers two levels – monetary and intellectual. The domestic nodes of an EM system should be affordable to the average consumer in price, but also in its configuration and maintenance, which should be simple and not require any professional help, as a way to facilitate a widespread adoption and consequently its impact.

**Table 6** **Evaluation of various energy management systems (2/2) [49].**

| (...) | Affordability | Control | Security & Privacy | Intelligence and Analytics |
|---|---|---|---|---|
| **PERSON** [50] | Low cost and low power consumption; | Manual remote control of the switches and dimmers in the home; | No | Context-aware intelligent algorithm; |
| **WattDepot** [51] | Open source, freely available; | No | Limited privacy model; | No |
| **ViridiScope** [52] | Requires indirect sensors; No in-line installation required; | No | No | No |
| **Mobile Feedback** [53] | High availability through mobile phone app; | No | No | No |
| **DEHEMS** [54] | Requires sensors; | No | No | Provision of energy-saving tips; |
| **EnergyWiz** [55] | Requires mobile app installation; | No | No | No |
| **NOBEL** [56] | Requires mobile app installation; | No | Yes | Limited (User behaviour analytics); |
| **ALIS** [57] | Requires extensive installations; Less affordable; | Yes | No | No |

Control distinguishes automation from consumer manual actions as its two forms. As depicted before, most of the EM systems implemented with control features today are focused on automation.

Security and Privacy poses a constraint to the EM systems, as these should be well protected.

Finally, Intelligence and Analytics are crucial to ensure that the consumer is able to use the information it is provided with, as it often lacks a deep understanding of electrical systems and has limited time to make energy-related decisions. If behavioural change is a goal, the data should be processed in such a way that the outcoming result clearly states the necessary action to be performed by the consumer. If automation-focused systems are considered, then it is desirable to have the system performing intelligent actions that balance energy consumption and consumer comfort, through the use of this intelligence. Both approaches require techniques such as machine learning, human–computer interaction, and "Big Data" analytics to discern usage patterns and predictive actions.

Table 5 and Table 6 show a resume of these requirements' analysis for the eight EM systems considered by Saima et al. Two of these EM systems, PERSON and DEHEMS, are further described and compared in the following paragraphs of this document.

PERSON, which stands for Pervasive Service-Oriented Networks, is a framework for EM systems implemented by Yang and Li (2010) [50]. This framework has three layers – A Heterogeneous Network Platform (HNP) that provides the exchange of information to the upper layers through the use of API's, a service-oriented network that abstracts the functionality in the form of services, thus supporting modularity and inter-operability, and finally a context-aware intelligent algorithm layer that incorporates intelligence for dynamic control and system optimization.

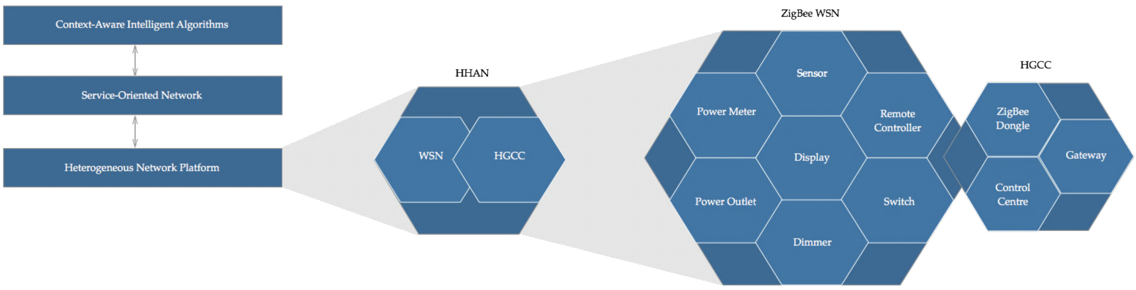


**Figure 12** **Illustration of the PERSON EM system implementation main blocks [50].**

Without a loss of generality, PERSON's implementation of the HNP is defined as a Heterogeneous Home Area Network (HHAN), comprises energy meters, power outlets, sensors, displays, remote controllers, switches, and dimmers, and uses a ZigBee Wireless Sensor Network (WSN) for communication. The system's Home Gateway and Control Center (HGCC) handles the collection, storage, and transmission of data, supports monitoring and control, and allows intelligent analysis and decision-making. It also integrates a Data and Service Centre (DSC) that can be used by consumers to get energy related information such as the average consumption of its given community. The system is said to be low cost but no value is presented to allow an accurate comparison with other implementations. It features low energy consumption, monitoring, automation-based control, but lacks in providing security and privacy [49, 50].

Sundramoorthy et al. (2011) [54] proposed a Digital Home Energy Management System (DEHEMS) that collects user experiences and preferences, and provides actionable feedback to consumers – The DEHEMS project brings together three key facets, behavioural change and technology along with a broader community context. DEHEMS framework is similar to that of PERSON, as it also relies on a sensor network connected through the ZigBee protocol to a central gateway. It supports the collection data from electrical and gas supply lines, individual appliances, and ambient sensors, but also supports a display for the real-time monitoring of energy use, historical use, energy-saving tips, and the comparison with the average use of all the users that are part of the system. The main features of the current implementation are relative comparisons with similar households, disaggregated appliance-specific feedback, support for setting goals and targets for the consumer, provision of energy-saving tips and environmental facts, and a social-network connection for information sharing. DEHEMS distinguish itself with its declared focus on user-driven energy improvement.

Saima evaluates the emerging trends that may lead to the future of EM systems and concludes that their main challenges are mostly related to interoperability and security. It states the growing importance of mobile devices and remote access to information, as these can serve as a tool for near-real-time communication with consumers, whose behaviour adjustment may lead to instant triggers that may impact on their energy consumption, carbon footprint, and dynamic energy tariffs.

According to this study, EM systems can serve as a useful tool towards active *demand side energy management*, one of the fundamental goals of smart grid – to influence the consumers' energy use behaviour, to either turn on/off or reschedule the use of their appliances. It concludes though that this requires a better understanding of energy use within homes and their impact on overall consumption in the smart grid. To achieve this, "many of the EM systems may be adopted by local utility companies and offered to customers at subsidized prices to make them more affordable. The utilities may also offer energy efficiency tips to the consumers through the EM system. In the long term, this helps the utilities to meet their sustainability and energy efficiency goals, while making their operations more reliable and cost effective" [49].

Saima further emphasizes that EM systems should also provide a framework for goal setting and allow consumers to track their progress toward their self-specified goals related to behaviour change, as a way to successfully incite the consumers to improve their behaviour continuously and under a long-term.

To conclude this review, Table 7 presents an overview of the type of interventions identified in the literature and the outcome indicators measured. The most common intervention was information provision (employed in 40 out of 48 interventions), followed by those focusing on social-psychological processes (34 interventions) and monitoring (31 interventions). All the behaviour specific indicators were self-reported, none was observed [62].

**Table 7** **Mapping of intervention types found in the literature [62].**

| | Intervention | | | | | | | | | | Indicators | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Category | Conven-ience | | Information | | Monitoring | | Social Psychological Processes | | | | Observed (O) or self-reported (S) | |
| Sub-type | Making it easy | Prompts | Justifications | Instructions | Feedback | Rewards | Social Modelling | Cognitive Dissonance | Commitment | Goal Setting | Aggregate energy use | Behaviour specific |
| Total by sub-type | 3 | 3 | 8 | 38 | 26 | 6 | 27 | 4 | 12 | 6 | 27 | 33 |
| Total by category | 4 | | 40 | | 31 | | 34 | | | | | |
| Abrahamse et al. (2007) Energy Analysis | | | | ■ | ■ | | | | | ■ | S | S |
| Allcott (2011) Evaluation of Opower studies | | | | ■ | ■ | | ■ | | | | O | S |
| Ayres et al. (2009) Puget Sound Energy | | | | ■ | ■ | | ■ | | | | O | |
| Ayres et al. (2009) SMUD | | | | ■ | ■ | | ■ | | | | O | |
| BC Hydro (2011) BC Hydro Power Smart | | | | | | ■ | ■ | | ■ | | O | |
| Benders et al. (2006) Energy Analysis | | | | ■ | ■ | | | | | | S | S |
| Bertrand et al. (2011) Lose your excuse | | | ■ | ■ | | | | | | ■ | | S |
| Borrell & Lane (2009) Kildonan UnitingCare | | | | ■ | | | | | | | O | |
| Brook Lyndhurst & Ecometrica (2011) CCF | ■ | ■ | | ■ | | | | | ■ | ■ | | S |
| Carlsson-Kanyama et al. (2007) Women vs. Men | | | | ■ | ■ | | | | | | | S |
| Carroll & Berger (2008) Colorado | | | | ■ | | | | | | | | S |

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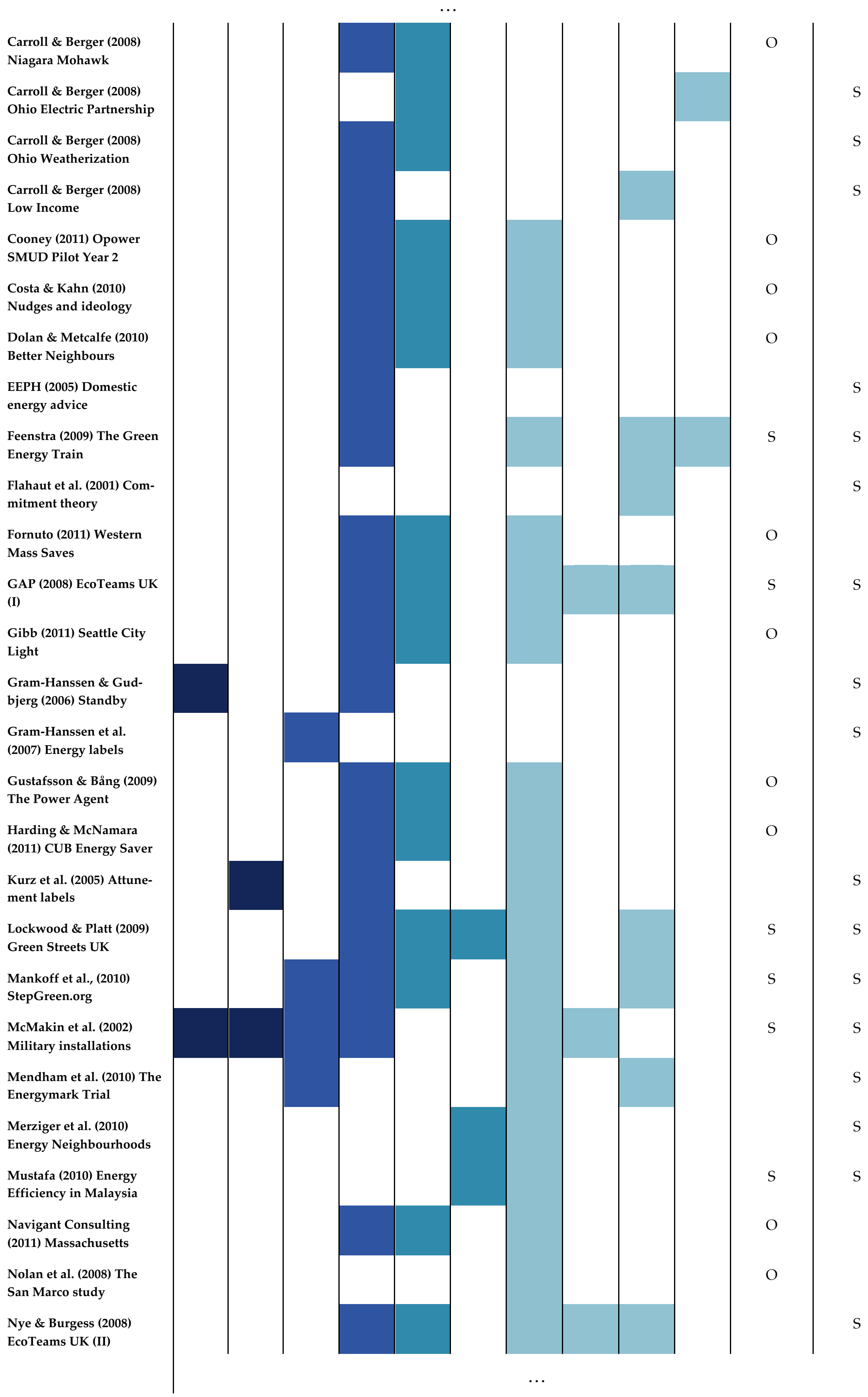
…
Carroll & Berger (2008) Niagara Mohawk
O
Carroll & Berger (2008) Ohio Electric Partnership
S
Carroll & Berger (2008) Ohio Weatherization
S
Carroll & Berger (2008) Low Income
S
Cooney (2011) Opower SMUD Pilot Year 2
O
Costa & Kahn (2010) Nudges and ideology
O
Dolan & Metcalfe (2010) Better Neighbours
O
EEPH (2005) Domestic energy advice
S
Feenstra (2009) The Green Energy Train
S
S
Flahaut et al. (2001) Commitment theory
S
Fornuto (2011) Western Mass Saves
O
GAP (2008) EcoTeams UK (I)
S
S
Gibb (2011) Seattle City Light
O
Gram-Hanssen & Gudbjerg (2006) Standby
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Gram-Hanssen et al. (2007) Energy labels
S
Gustafsson & Bång (2009) The Power Agent
O
Harding & McNamara (2011) CUB Energy Saver
O
Kurz et al. (2005) Attunement labels
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Lockwood & Platt (2009) Green Streets UK
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Mankoff et al., (2010) StepGreen.org
S
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McMakin et al. (2002) Military installations
S
S
Mendham et al. (2010) The Energymark Trial
S
Merziger et al. (2010) Energy Neighbourhoods
S
Mustafa (2010) Energy Efficiency in Malaysia
S
S
Navigant Consulting (2011) Massachusetts
O
Nolan et al. (2008) The San Marco study
O
Nye & Burgess (2008) EcoTeams UK (II)
S
…

…

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nyrud et al. (2008) Wood-stoves** | | | | | | | | | | | | S |
| **Palm (2010) Energy consultants** | | | | | | | | | | | | S |
| **Peschiera et al. (2010) The response–relapse study** | | | | | | | | | | | O | |
| **Robinson, S. (2009) Manchester Is My Planet** | | | | | | | | | | | | S |
| **Staats et al. (2004) Eco-Teams Netherlands** | | | | | | | | | | | S | S |
| **Union Fenosa (2007) Energy Efficiency Index** | | | | | | | | | | | | S |
| **Valuntiené (2009) Taupukas residential awareness** | | | | | | | | | | | | S |
| **Ward et al. (2011) Transition Streets** | | | | | | | | | | | | S |
| **Schultz et al. (2007) San Marco experiment** | | | | | | | | | | | O | |
| **Wortmann et al. (2003) Off. Really off?** | | | | | | | | | | | | S |

## 3.2 The Internet of Things

The Internet of Things (IoT) is defined by ITU and IERC as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual '*things*' have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network" [42]. IoT is set as a global concept based on the idea that anything can be connected at any time from any place to any network, by preserving the security, privacy and safety.

Today the IoT is one of the trendiest and most rapidly spreading consumer-centred technologies. It is predicted that 50 to 100 billion things will be electronically connected by the year 2020 [42]. This phenomenon is easily explained by data regarding Internet usage by humans today. Meeker et al. presents recent data regarding the Internet usage worldwide penetration and the average time spent per adult user per day in the United States, as shown in Figure 13 and Figure 14, respectively.

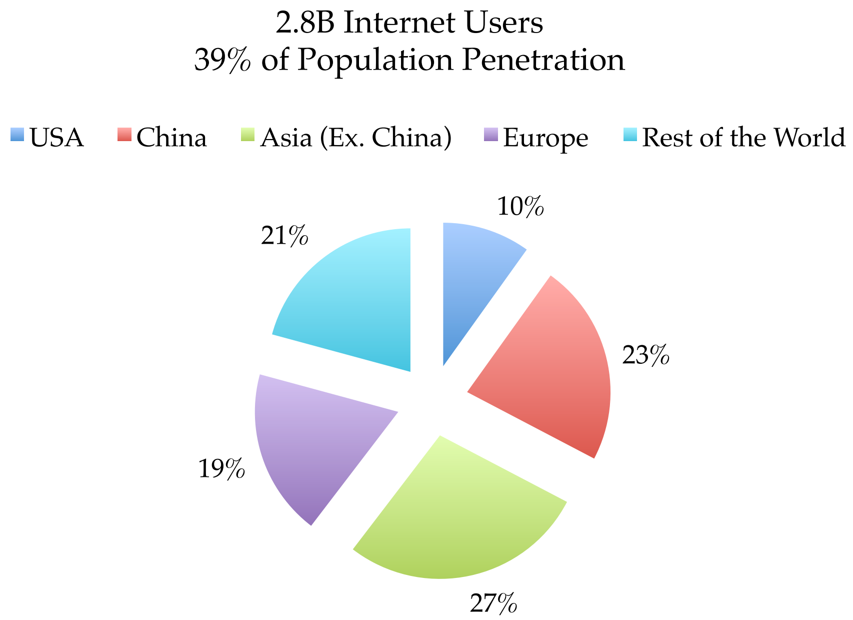



**Figure 13** **Worldwide Internet penetration by 2014 [44].**

With already close to 6 hours a day spent, on average by adult user on the USA, consulting online digital media, 51% on a mobile setting, the growth of the number of connected devices, aiming to extend their value with innovative services built online to serve the constantly connected portion of a population, seems an inevitability – It evolved from being a futuristic academic subject to an actual market fit technology.

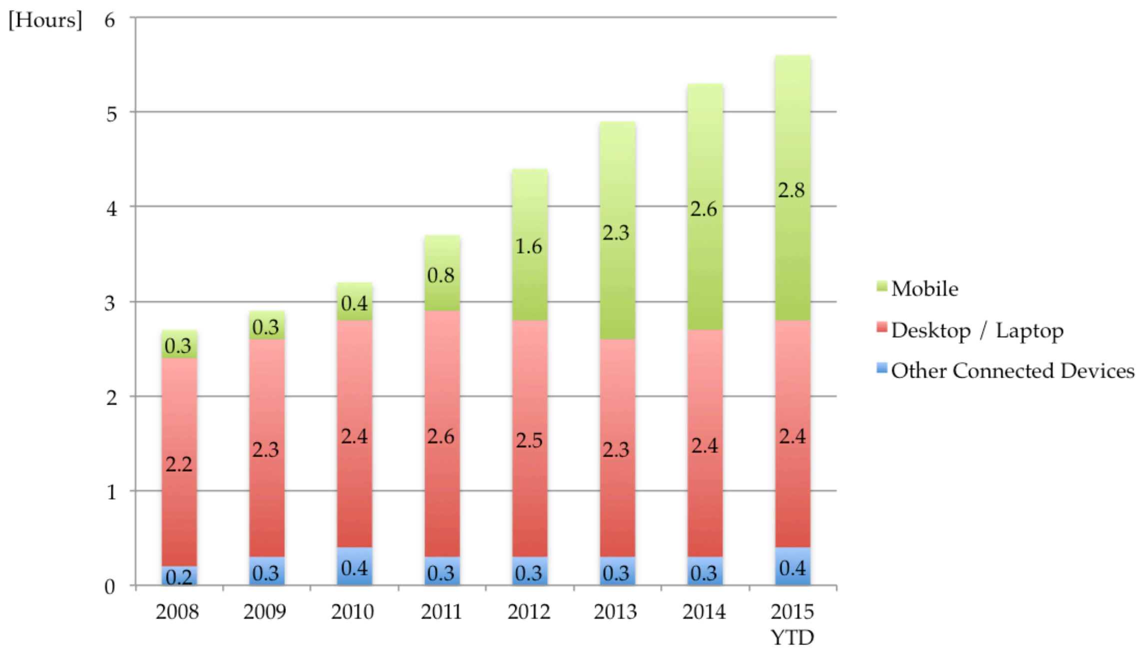



**Figure 14** **Time spent per adult user per day with digital media, USA, 2008 – 2015 YTD [44].**

But as these *things* number is scaling so it is the heterogeneity of this class of objects – Justified by the fact that each object tends to have a very specific set of purposes, constraints and surrounding settings – which is, at the time, not leading to a *winner takes it all* situation in which a single standard is imposed. Vermesan et al. states that "on the way towards *'Platforms for Connected Smart Objects'* the biggest challenge will be to overcome the fragmentation of vertically-oriented closed systems and architectures and application areas towards open systems and integrated environments and platforms, which support multiple applications of social value by bringing contextual knowledge of the surrounding world and events into complex business/social processes" [42].

This heterogeneity reflects into several building blocks of the IoT technology – as in its *Cloud* services' access and data storage and management (commonly referred to as *Middleware*), actuators embedding and communication protocols used. Table 8 holds a list of the most common short-range communication protocols used within the IoT, their main characteristics and common applications.

**Table 8** **Popular short-range wireless technologies' comparison [40].**

| Technology or Standard | Frequency or Wavelength | Range | Features | Common Applications |
|---|---|---|---|---|
| **ANT+** | 2.4 GHz | < 10 m | Low power | Health, sports monitoring |
| **Bluetooth** | 2.4 GHz | < 10 m, up to 100 m with higher power | Low power version available | Wireless headset, audio apps |
| **Cellular** | Common cellular bands | Several Km | Longer range | M2M |
| **IEEE 802.15.4** | 2.4 GHz | < 10 m | Multiple protocols available | Wireless networks |
| **IEEE 802.22** | 470 to 768 MHz | Many miles | Designed for white spaces, cognitive radio | Broadband, backhaul, not yet used |
| **ISA 100a** | 2.4 GHz | < 10m | Extra security and reliability | Industrial monitoring and control |
| **Infrared (IrDA)** | 800 to 1000 μm | < 1 m | Security, high speed | Remote control, data transfer |
| **ISM Band** | Part 15 frequencies | < 10 m | Low cost, simplicity | Monitoring and control |
| **NFC** | 13.56 MHz | < 30 cm | Security | Payment, access |
| **RFID** | 125 KHz, 13.56 MHz, 902 to 928 MHz | < 1 m | Low cost | Tracking, inventory, access |
| **6LoWPAN** | 2.4 GHz | < 10 m | Internet access | Monitor and control via Internet |
| **UWB** | 3.1 to 10.6 GHz | < 10 m | Low power, high speed data | Video transfer |
| **Wi-Fi** | 2.4 and 5 GHz | < 100 m | High speed, ubiquity, widely available infrastructures | Local networks, Internet access, broadband |
| **Wireless HART** | 2.4 GHz | < 10 m | HART protocol | Industrial monitoring and control |
| **WirelessHD** | 60 GHz | < 10 m | Very high speed | Video transfer |
| **WirelessUSB** | 2.4 GHz | < 10 m | Proprietary protocol | HID |
| **ZigBee** | 2.4 GHz | < 10 m | Mesh networks | Home, industry monitoring and control |
| **Z-Wave** | 908.42 MHz | < 30 m | Simple protocol | Home monitoring and control |

Several constraints constitute the reasons that are leading to this heterogeneity, including energy limitation, reliability required from the wireless medium, security and privacy concerns, monetary cost of the node devices, radial distance between two nodes, spectrum noise, limit size of the node devices, available infrastructure, private technology and others. But the scarcity of energy resources available in the embedded devices is a sensitive and common issue, as it is one of the main barriers to a widespread deployment of the IoT technology, although a number of solutions have been introduced in the literature to increase these devices' energy efficiency. For instance, lightweight MAC protocols, energy efficient routing protocols, and tailored security protocols have been proposed to mitigate the impact of resources scarcity on sensing technologies. But their limited autonomy still remains a problem [43].

Many of the IoT based solutions that technology manufacturers are focused on are intended to automatize processes and exclude the human from the feedback loop. The focus on automation features, through the devices' actuators, is also contributing to this heterogeneity. This is justified by the fact that the automatized subject and its main characteristics vary considerably. Even considering a same category, as for example refrigerators, its construction specifications and its brand's standards undertake the possibility of the development and thrive of a common standard for embedding IoT-powered actuators.

The middleware can be defined as the software layer that binds the physical layer (e.g the hardware) with the application one, and it is responsible for providing the abstraction required from the heterogeneity and complexity of the underlying technologies of the physical layer. As so, the middleware is the major contributor to the IoT's interoperability today. Romdhani et al. states that Service-oriented Computing (SoC) lying on cloud infrastructures is opening a door to a highly flexible and adaptive middleware, and that this may even lead to decoupling the sensors' ownership from its usage and consequently to a set of sensor services to be exploited in different applications for different users through the cloud. Romdhani et al. concludes that "decoupling the application logic from the embedded devices, and moving it to the cloud will allow developers to provide applications for the heterogeneous devices that will compose the future IoT environment" [43]. As a part of this new approach to the middleware layer, the flexible, non-SQL databases are also contributing to the abstraction of the heterogeneity complexity. These types of databases do not require any a-priori set of rules defining the relationships between their basic storage elements nor their types. This allows that on any time a new storage entity may be defined and introduced at these databases, for example corresponding to a new device type, different from those deployed in the past on a sensor network, which may also connect to other entities, in a storage layout point of view.

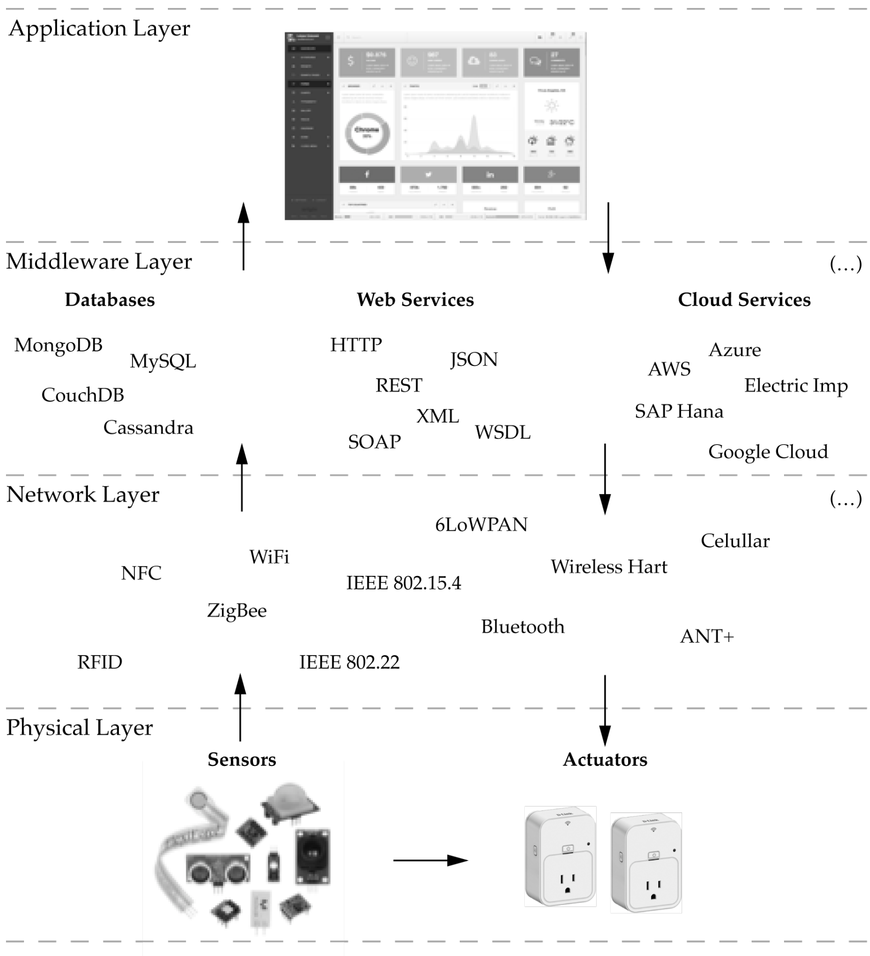



**Figure 15** **Illustration of the several layers of the IoT and it heterogeneity.**

Although thorough standardization seems a distant reality to the IoT, due to the previously presented scenario of heterogeneity, some effort is being done to combine standards of the several layers into common platforms that may lead to a better short-term interoperability and also to the faster deployment of new IoT technology. This study confronts three of these platforms – The Electric Imp, the Intel Edison and the Particle.io Photon. Table 9 shows the specifications of these three products.

Regarding connectivity the three rely primarily on the use of WiFi. Although WiFi was firstly introduced as a technology to grant a fast throughput over a wireless medium and to guarantee the quality of service of streaming of

**Table 9** **Comparison between three IoT-Ready platforms – The Electric Imp, Intel Edison and Particle.io Photon.**

| Specifications | Electric Imp (imp 002) | Intel Edison | Particle.io Photon |
|---|---|---|---|
| **Network Connectivity** | **802.11 b/g/n 2.4 GHz WiFi** | **802.11 a/b/g/n 2.4/5 GHz WiFi (Dual band)**<br>**Bluetooth 4.0** | **802.11 b/g/n 2.4 GHz WiFi** |
| **I/O Interfaces** | **12 user selectable I/Os**<br>GPIO, PWM, Analog input & output, SPI (2 channels), UART (4.5 channels), I2C (2 channels); | **40 user selectable I/Os**<br>GPIO, PWM, Analog input & output, SPI, UART, I2C, I2S, USB, SD Card; | **18 user selectable I/Os**<br>GPIO, PWM, Analog input & output, SPI, UART, I2C, I2S, CAN, USB; |
| **Internal Processing Power** | 32-bit Cortex M3 processor 120MHz; | Dual Core Intel Atom CPU at 500MHz;<br>32-bit Intel Quark micro-processor at 100 MHz; | 32-bit Cortex M3 processor 120MHz; |
| **Internal Memory** | 80KB RAM for application use;<br>128KB RAM for code storage; | 1 GB LPDDR3 POP;<br>4 GB eMMC flash storage; | 128KB of RAM;<br>1MB of flash storage; |
| **Low Power Operation** | 6μA sleep mode; | 1mA to 5mA sleep mode; | 80μA sleep mode; |
| **Operating Temperature** | -20°C to +55°C | 0°C to +40°C | -20°C to +60°C |
| **User Configuration Process** | BlinkUp,<br>Optical configuration technology; | None,<br>Developer Implemented; | None,<br>Developer Implemented; |
| **Cloud Service** | Cloud Agent dedicated to every device;<br>Over-the-air firmware updates;<br>Free for limited and noncommercial use; | Intel IoT Analytics Platform (beta);<br>Intel® Mashery™ (REST) API Network;<br>Integrated Microsof Azure;<br>Integrated Amazon Web Services;<br>Integrated IBM Bluemix;<br>Free for limited and noncommercial use; | REST API;<br>Over-the-air firmware updates;<br>Free; |
| **Unit Price (same retailer)** | 25.50 USD | 59.94 USD | 22.50 USD |

media content across the Internet, a very different setting from that of the sensor networks which typically do not require such a heavy throughput, WiFi is seen as a short-term winner for allowing a fast deployment of IoT, specially when domestic applications are considered, due to the fact that infrastructures for its use are already well disseminated among households. The price to pay is related to power consumption, as the WiFi is not easily reconfigurable to allow the use of just a portion of its throughput capability, which leads to a considerable overhead and a high power consumption for commonly very power conscious applications. To increase the devices' autonomy the developers would have to forgo the idea of having a constantly connected device and minimize the total time of WiFi connectivity, by connecting periodically and keeping it at a low power, WiFi-off state in between, in such a way that the devices' features are not put at stake.

The Electric Imp is the solution that draws a lower current while in the sleep mode. The 6μA value makes it possible for a device to typically hold for around two years running on two AA batteries, while operating with periodic connections to the WiFi network. Photon follows behind, but with a sleep current more than 10 times larger (80μA). Edison clearly loses this race with its lowest current drawn ranging around 3mA – which would consume the same AA batteries in just a few hours.

Edison's poor results on power saving is justified by its processing power. Here Edison is definitely the winner, as its processor is able to compete with that of a desktop computer from the beginning of the new millennium. The same can be said about the internal memory, with 1GB of RAM and 4GB of flash storage. Edison clearly presents the most powerful hardware, but as most IoT applications simply rely on the hardware for reporting short pieces of data from a collection of sensors, and as cloud solutions for a latter heavier processing of this data are thriving, its seems as many developers may consider its powerfulness as an unnecessary overhead that puts at stake the lifespan of the device. The Electric Imp and the Particle.io Photon share the same processor, a 32-bit Cortex M3 processor that runs at 120MHz, and approximately the same memory configuration, based on 128KB of RAM. Photon adds 1MB of flash storage.

The types of interfaces put available by the three platforms are closely the same, but Edison superimposes itself with more than the double of the available ports regarding its competitors, with 40. Photon follows with 18, and the Electric Imp closes the ranking with 12.

Note to the operation temperatures of the three devices, as Edison falls behind in versatility with its lower threshold set at 0°C while the two competitors grant operation at -20°C, and its higher at 40°C, minus 20°C and 15°C than the Photon and the Electric Imp, respectively. This may put at stake the introduction of the Edison technology at some domestic appliances, such as freezers or washing machines, if a proper isolation is not achievable for its purpose.

As a user gets a device powered by any of these platforms, the first thing that it will have to do will be to configure the device so that it knows to which network it should connect to, and which security credentials should it use to grant itself access to it – Commonly, the user will have to insert the network's SSID and WEP password into the device. The Electric Imp adds a proprietary technology called BlinkUp that allows a simple configuration through an optical process. All the Electric Imp devices come equipped with light sensing capabilities that allow the recognition of light pulses. This means that the network's credentials can be sent to the device by coding and flashing this information into light pulses, which can be performed by any mobile device, as a smartphone or tablet. This process simplifies considerably the on-boarding of any IoT device into a new home. With the Edison and Photon this process needs to be customized by the developer, and it is commonly done through a USB connection of the IoT device to a desktop or mobile device.

The Electric Imp also distinguishes itself by having a portion of a server's computation dedicated exclusively to every single device – which is called the device's Agent. The Agent is the entity responsible to set a web-interface to the device. Every web-based communication from or to a device has its Agent as the intermediary. The Electric Imp Cloud also sets over-the-air automatic firmware updates to the device. Edison brings a seamless integration with several third party services, as Amazon Web Services or Microsoft Azure. The Photon puts available a REST API to remotely connect to every device and it also grants over-the-air firmware updates.

The consideration of these platforms' unit prices determines three very typical profiles. The Electric Imp assumes the value-for-money position, with the second lowest unit price and a difference to the first that may be justified by the features of low power consumption and the simplicity of the BlinkUp process. Edison seems tailored for power applications, with infinite power available, that require heavy local processing, with the powerful specifications raising its price and power consumption to the highest. Finally Particle.io Photon shows up as the simplest and most versatile implementation, and the lowest unit price of the three, but with less convenience features than the Electric Imp.

4

# Implementation

## 3.1 The Device

The analysis of the energy sector context, namely the understanding of a need to engage customers and to have big data harvested from a large amount of households to learn about their consumption patterns, led to four major constraints regarding the concept behind the developed device – It should be *affordable*, so that it could be easily distributed among the consumers, even if this would bring less accurate readings, it should be *easy to install and to use*, without any need of technical support as that required by interventions on host appliances' circuits, and consequently without any dependence on specific brands or appliances, it should be *adaptable* to several sources of behaviour motivated energy waste on households and finally it should be *appealing* on its shape and physical feedback, specially to families and children.

These constraints led to several iterations on the device's hardware and shell. The final product of these iterations was an egg shaped device, connected to the web via WiFi, composed by a set of environmental sensors to infer about energy efficiency impacting behaviours, and that would make the user aware of these behaviours in real-time through beeping victory or defeat melodies. This device was called EGGY.

The egg shape is justified by the merits that an organic and personified device brings. The EGGY was designed to become a friendly pet that lives by harvesting the energy that the users' save. The egg shape was chosen for being a simple and easily personified one, able to appeal both to adults and children.

The WiFi connectivity was chosen because of the *affordability* and *easiness to install and to use* constraints. WiFi is widely available in households today.

Using this infrastructure avoids the need of setting a bridge device, other than the already existing WiFi router, to manage the connection between the web and the device. By avoiding this need to add an extra device to manage the Internet connection the total production cost of the solution becomes lower. At the same time it also makes the device's configuration process to be a lot more straightforward, even for the least tech-instructed user. This configuration process would be achieved with a technology called *BlinkUp*, which allows the user to optically configure the device by setting the screen of its mobile smartphone or tablet to blink the WiFi network's credentials. A phototransistor at the bottom of the EGGY device would detect the flashes and decode this into information. While offline, this would be the only interface between the user and the device. After getting online, a web platform would become the main interface between them. More about this process is described further ahead on chapters 3.1.2 to 3.1.4 of this document.

**Figure 16** **The egg shaped device, named EGGY.**

The focus on behaviour monitoring is based on the understanding of how these can be impacting on a household's energy consumption, not only by the savings that they can potentially generate but primarily because of how effortlessly this could be achieved just by adjusting the right triggers. It was understood that a change in the paradigm regarding the energy efficiency promoting products was needed if a mass-appealing product was to be seek. The cash-back focused solutions based on appliances' accurate energy consumption readings were considered to be failing due to three main reasons – Investment, comprehensibility and consequentiality.

The first reason is easily explained, as the investment that these solutions propose is turning them into weak sellers. For achieving the goals proposed, namely the engagement of the energy consumers towards their savings and the harvesting of big data regarding the households' consumption patterns, building a community of users was considered to be a priority, and this would be impossible to achieve with a device, or a set of them, that just a small share of the population of a developed country could afford. The precision of the data harvested was considered to be conflicting with the need of recognizing patterns from sampling a big number of households. For this to be done, it was concluded that a democratization of the device was needed, in price, but also on comprehensibility and consequentiality.

What is meant with comprehensibility is to refer to a measurement of how easy it is to engage with the harvested data. These devices are sharing information that most users cannot comprehend nor assess. Electricity consumption readings are values that consumers struggle to decode, in particular if no baseline values are available to perform a comparison, which is often the case. On the contrary, behavioural data is considered as one kind that every user can relate too, even non tech-instructed users, as it is based on their own daily-life actions.

Consequentiality comes from what the users can do with the harvested data. The consumption readings were considered to be inconsequent. As it doesn't allow a screening to separate the behaviour contribution from the appliances' standard consumption, and keeping up with the consumption deviations is something that only engineering minded consumers could be willing to do, what they promote is a replacement of old appliances for new, more efficient ones. Because this is not an investment that consumers are often available to do, all consequentiality is lost. Conversely, focusing on behavioural data and improvements may lower the bar on the hypothetical maximum savings but it raises the prospects of having an effective engagement towards the energy efficiency of their current appliances, which take us to the old saying about having a bird in the hand or two in a bush. It was considered that the best practice would be to minimize the consumers' investment on energy efficiency and instead provide them with low-investment tools to improve the current appliances, in particular for the big - and most impacting - ones, such as the refrigerator.

The decision on the kind of sensors to be packed inside EGGY relied on the need to have a wire-detached device that would turn it mobile enough to be easily interchanged between several sources of behaviour related energy waste at home, and to grant it the merit of being independent from any appliance and its type or brand, and consequently to be ready for any web connected household. To achieve this it was decided that the device should be provided with a collection of environmental sensors, as temperature, light, movement, sound and humidity ones.

As the main goal of the device would be to make the user aware of its energy efficiency impacting behaviours it was designed to use the human as its actuator, instead of using automatized control features that would not only diminish the impact on behaviour awareness but also need a less adaptable, more appliance-dependant solution that would harm the objective of having an affordable and easy to install device ready for a large set of households.

A considerably affordable implementation would be achieved, which would lead to a production cost close to 15€, lowerable with scale. This was considered to be a value that would improve its massification prospects, regarding the state-of-the-art analysed, and allow the involvement of utility companies as distributors of the technology with subsidized prices for their customers, motivated by their sustainability and energy efficiency goals.

### 3.1.1 Hardware Specifications

The designed device is composed by three main elements – The EGGY Shell, the EGGY Board and the power supply.

#### 3.1.1.1 EGGY Shell

The EGGY Shell encloses the electronics inside it. It was designed under the constraints of size, robustness, touch and visual appeal, manufacturing complexity and costs, and isolation.

**Figure 17** **The EGGY Shell, with its top and bottom parts isolated.**

Due to mold manufacturing and EGGY assembling costs the shell was designed to have two separate pieces – A bottom and a top one, as depicted in Figure 17. The bottom part of the shell characterizes itself by a flat base, in which some support ledges guarantee the fix position of the EGGY Board over it. Three holes on the bottom are left open for a phototransistor, a bi-colour LED and a sliding power switch. These components functionality is described in the following section 3.1.1.2 of this chapter, regarding the EGGY Board.

The top part of the shell encloses the EGGY Board inside it. The edge of the rim assures a surface to join the two parts together. A reduction of the shell's thickness towards the top ensures that the shell's opacity is not impacting on the device's capability to detect small, but still relevant for the targeted use case, values of light intensity.

The shell was made of Acrylonitrile Butadiene Styrene (ABS), a thermoplastic polymer known for its impact resistance and toughness, coloured with a white pigment. Tests over light opacity were conducted upon the decision of this material and pigment percentage, which were passed successfully. This material is also known from experience to perform normally in refrigerators, as it is the common choice for the refrigerators' shelves and accessories.

Figure 18 shows the dimensions of the EGGY Shell, measured with a caliper rule.

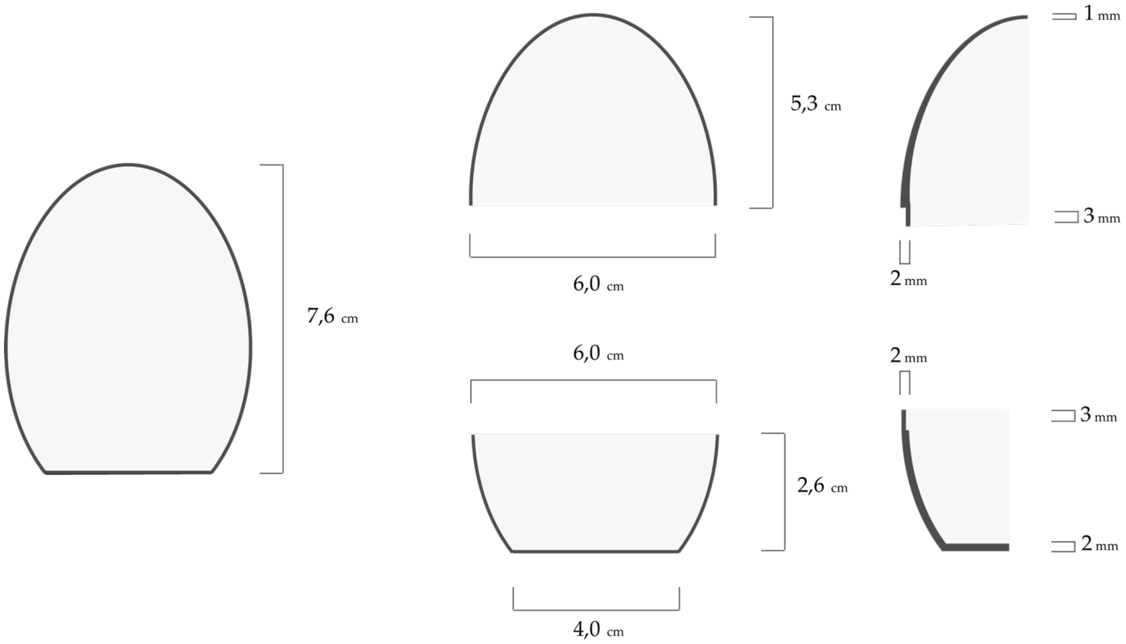



**Figure 18** **The EGGY Shell's dimensions.**

#### 3.1.1.2 EGGY Board

The EGGY Board was built as a Printed Circuit Board (PCB) and using mount-on-top components. It relies on an Electric Imp chip to perform as a microprocessor and manager of the WiFi connection, which is surrounded by auxiliary circuits to perform sensor readings and actuators triggering. This version of the device would count with temperature and light intensity sensors, as the refrigerator use case would be the one chosen to validate the concept, and these would be enough for acquiring the energy efficiency impacting behaviours towards it. A buzzer to play victory and defeat melodies according to the user's real time behaviours was embedded as the actuator. Figure 19 shows the assembled board.

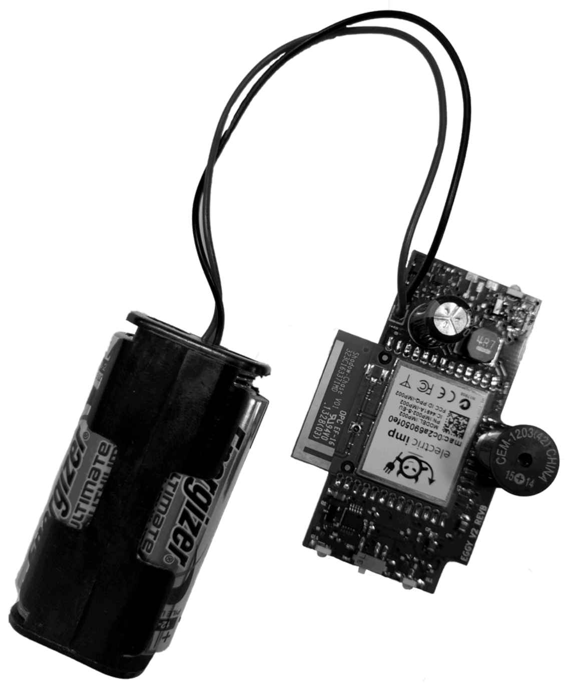


**Figure 19** **The EGGY Board.**

Five main circuits were defined and designed – The Power Supply Circuit, the Electric Imp Circuit, the Temperature Sensing Circuit, the Light Sensing Circuit and the Buzzer Circuit. Figure 20 shows the schematic for these main building blocks that compose the EGGY Board.

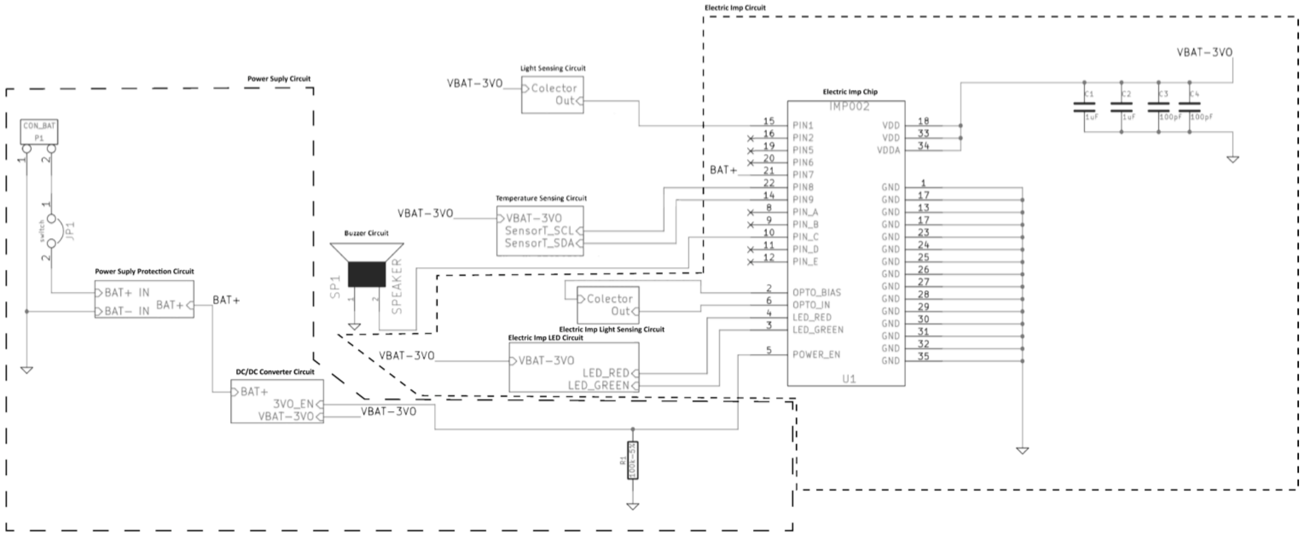



**Figure 20** **Schematic featuring the main blocks of the EGGY Board.**

The Power Supply Circuit is composed by a power source, a switch, a power source protection circuit and a DC/DC voltage converter circuit. The Electric Imp chip, namely the WiFi hardware, would require a voltage set at 3.3V, a value that would be under the acceptance range for powering the rest of the components of the EGGY Board, and which, as so, would become the nominal operation voltage throughout the board. To provide this voltage, and after considering the constraints of the batteries' size and energy drain (refer to the following Power Supply & Energy Consumption section for more detail) the power source was dimensioned to be composed by two AA lithium batteries, which combined would set the voltage across their terminals to 3.4V at their best condition, and consider a maximum decay of 1.4V, until a voltage of 2.0V, over usage. A switch would follow the positive terminal of the power supply, which would be placed at the bottom of the EGGY, on the centre hole of the bottom part of the EGGY Shell, and used to turn on and off the power supply circuit and, consequently, the device.

A power source protection circuit would follow, which, as the name implies, would have the protection of the power source, namely against reverse power flow phenomena and voltage peaks, as purpose. The reverse power flow phenomena could happen due to the discharge curves of the capacitors along the whole circuit, in particular due to a high capacitance one (1000μF) which would be used at the DC/DC voltage converter circuit, and which existence will be justified further ahead. This would lead to an attempt of the circuit to charge the power supply, which could develop a short-circuit and damage the components. This protection circuit would also be used to ensure that the voltage across the terminals of the power source would never go under 2.0V nor beyond 3.3V.

Figure 21 shows the designed protection circuit. The chip's surrounding auxiliary circuit was based on the manufacturer's recommendations.

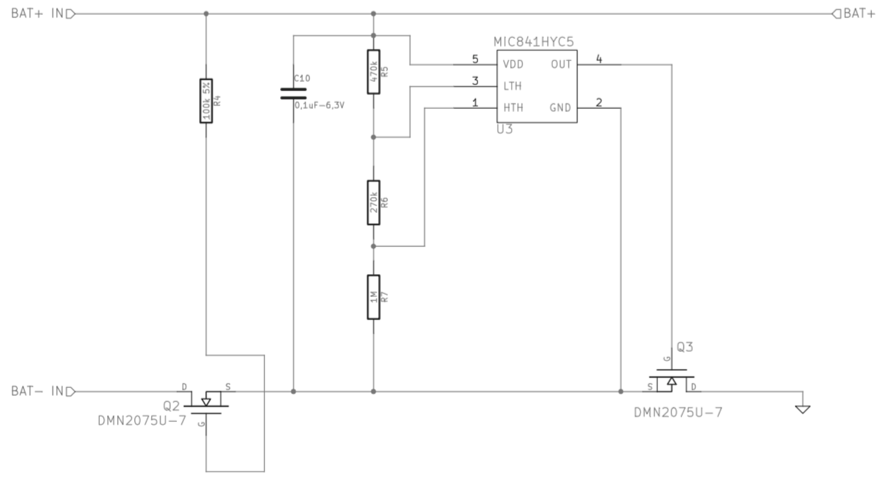



**Figure 21** **Schematic of the power source protection circuit.**

Following the power supply protection circuit, a DC/DC voltage converter circuit would be inserted to force a steady 3.3V voltage supply to the rest of the circuit. As the circuit is known to draw current peaks throughout its operation it was necessary to introduce some protection at this point. This would be guaranteed by introducing a large capacitance capacitor, valued at 1000μF, which would filter these peaks. To ensure a better operation of the following circuit a capacitor characterized by a smaller capacitance was also introduced, following the filtering of the peaks, to filter the smaller noise over the expected constant current. An enable pin of the DC/DC converter chip would be connected to the Electric Imp chip, which would disable the DC/DC converter chip whenever the Electric Imp would be put to sleep, as a means to save energy – The DC/DC converter would draw a current ranging around 2nA while enabled and around 2μA while disabled. To achieve this, a pull-down resistor would have to be included between the Electric Imp chip and the DC/DC converter to guarantee that a low level voltage is set while the Electric Imp chip is put to sleep – The voltage at its enable pin would stand floating if at this point by default.

A voltage divider at the end of the DC/DC converter circuit would set the desired output voltage to be 3.3V. Equation 1 presents the calculation of this output voltage, and Figure 22 shows the schematic of designed DC/DC converter circuit.

$$V_{BAT-3VO} = 0.45 \cdot (R_2 + R_3)/R_3$$

$$V_{BAT-3VO} = 0.45 \cdot \frac{270K + 43K}{43K} = 3.276V$$

**Equation 1** **Calculation of the DC/DC converter circuit output voltage.**

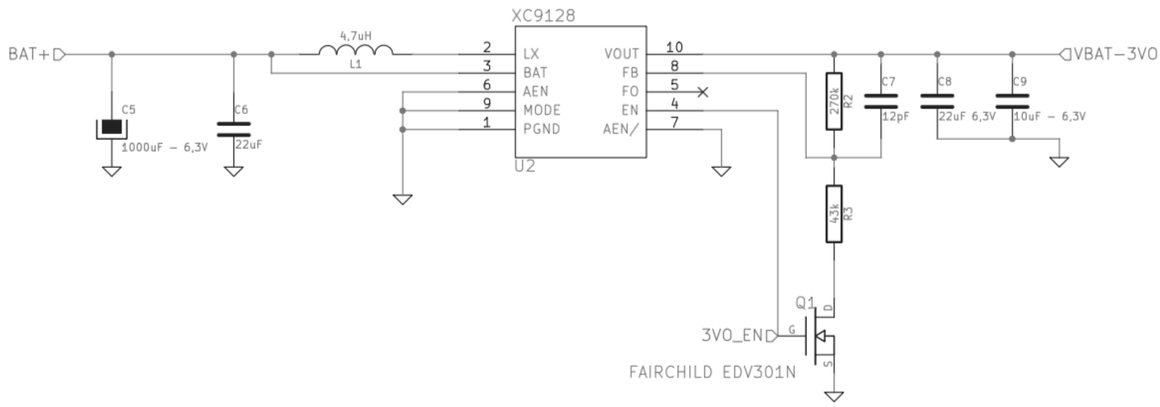



**Figure 22** **Schematic of the DC/DC converter circuit.**

The Electric Imp Circuit is composed by the Electric Imp chip and its light sensing and LED circuits. The Electric Imp chip is characterized by a WiFi module that can provide 802.11 b/g/n connectivity through 20MHz 11n channels with a typical sensitivity of -97dBm, corresponding to 1Mbps, and a 32-bit Cortex M3 microprocessor that provides 12 user selectable I/Os which can be configured as GPIO, PWM, Analog input & output, SPI (2 channels), UART (4.5 channels) and I2C (2 channels). This implementation would take use of an I2C input, connected to the output of the Temperature Sensing Circuit, a PWM output, connected to the input of the Buzzer Circuit, three GPIO, connected to the Light Sensing circuit and the Electric Imp light sensing and LED circuits, and an Analog input to sample the power supply voltage periodically.

Table 10 shows the electrical characteristics of the Electric Imp chip.

**Table 10** **The Electric Imp chip electrical characteristics.**

| Parameter | Description | Min | Typ. | Max | Unit |
|---|---|---|---|---|---|
| **Operating Temperature** | | -20 | - | 55 | °C |
| $V_{DD}$ | Operating voltage | 1.8[1] | 3.3 | 3.6 | V |
| $V_{DDA}$ | Analog power input | 1.8 | $V_{DD}$ | $V_{DD}$ | V |
| $I_{DD}$ | Normal operation, WiFi on | - | 80 | 250[2] | mA |
| | Normal operation, WiFi power-save mode enabled | - | 5 | 250 | mA |
| | WiFi is off, processor sleep, RTC on, nvram preserved | - | 6 | - | μA |
| $I_{DDA}$ | Current input on $V_{DDA}$ | - | 70 | 500 | μA |
| $V_{IH}$ | Input I/O high level voltage | $0.7V_{DD}$ | - | 3.6 | V |
| $V_{IL}$ | Input I/O low level voltage | $V_{SS} - 0.3$ | - | $0.3V_{DD}$ | V |
| $I_{OUT}$ | Output current on any single I/O pin | -8 | - | 8 | mA |
| | Output current on LED_RED pin | -20 | - | 20 | mA |
| | Output current on LED_GREEN pin | -20 | - | 20 | mA |
| | Total output current on all I/O pins including LED_RED & LED_GREEN | -80 | - | 80 | mA |
| **I/O Input Leakage Current** | $V_{SS} \leq V_{IN} \leq V_{DD}$ | - | - | 4 | μA |
| **Load Capacitance** | Pins 1 to 9 | - | 20 | - | pF |
| | Pins A to E | - | 5 | - | pF |

[1] The WiFi connectivity requires a minimum of 2.5V for operation, but the microprocessor can run alone powered by a 1.8V voltage. As depicted before, the DC/DC voltage converter circuit, enabled by the Electric Imp POWER_EN pin, is used to maintain an adequate voltage for WiFi connectivity requirements.

[2] 250mA current peaks can happen on worst-case TX events, which can last for a maximum of ~4.8ms long.

The Electric Imp light sensing and LED circuits would be used to perform the BlinkUp[3] and to give an instant feedback to the user about the device's operation status, respectively. The first is composed by a phototransistor, which generates an electric current across its Collector and Emitter pins according to the level of light intensity to which it is under, and a pull-down resistor to force a low level voltage whenever the phototransistor is not conducting. The LED circuit is composed by a bi-colour LED, which is used to create 3-colour (Red, orange and green) codes, surrounded by resistors to limit the drawn current according to the LED manufacturer's specifications.

Figure 23 shows the schematic for the Electric Imp LED and light sensing circuits.

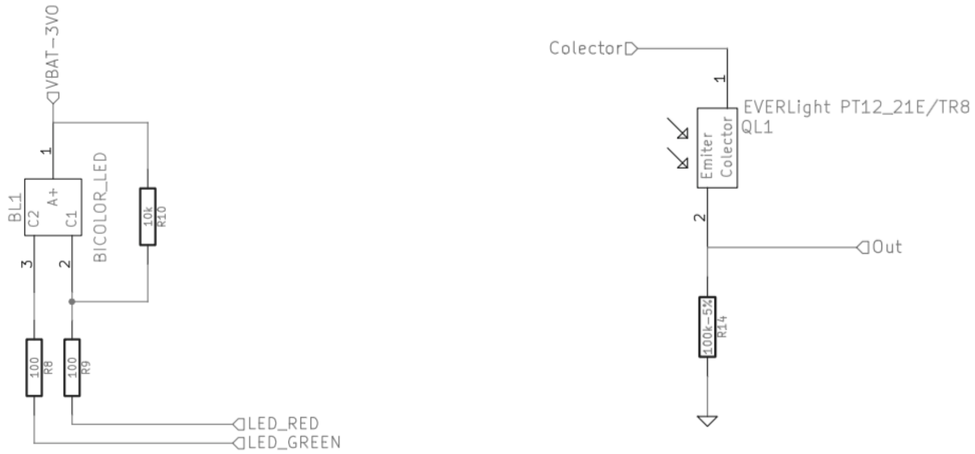



**Figure 23** **Schematics of the Electric Imp LED circuit (Left) and light sensing circuit (right).**

The Temperature Sensing Circuit is made up of a thermal sensor chip and a collection of surrounding auxiliary passive elements. The thermal sensor

[3] Optical configuration process, which uses light pulses from a screen of a smartphone or tablet to send the WiFi network's credentials to the device. This process is further detailed on section 3.1.2 of this Chapter.

chip uses the I2C protocol to communicate with any given microprocessor, in this case the Electric Imp, and establish a device-to-device bus. This protocol takes use of two bidirectional open-drain lines, called the Serial Data Line (SDA) and Serial Clock Line (SCL), pulled up by resistors, with the first having as purpose to transmit the data and the second the clock signals to synchronize the conversation between the devices. The fact that these lines are open-drain justify the need for the pull-up resistors – The chip can by itself force the voltage on any of the lines of a low level voltage, but not to a high level one. The option relies in using open-drain lines because these can ensure that no component-harming high currents are able to flow when two devices try and signal simultaneously. In order to communicate with each other on a one-to-one basis both devices need to be identifiable, which is done through 7-bit addresses. The last bit of this byte word is left for signalling if the message is being sent by the master to the slave — a *write* — or in the other direction — a *read*. The thermal sensor address, as on any other device, would be established by the manufacturer and presented at its datasheet.

Figure 24 shows the schematic of the Temperature Sensing Circuit dimensioned.

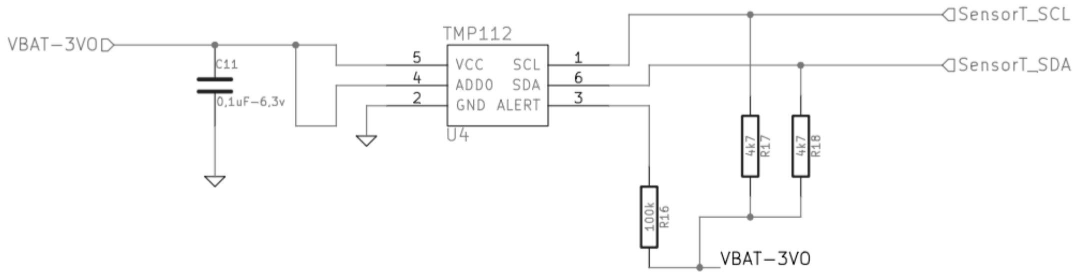



**Figure 24** **Schematic of the Temperature Sensing Circuit.**

The Light Sensing Circuit is composed by a phototransistor, a bipolar junction transistor (BJT) and a pull-down resistor. The output of this circuit is connected to a GPIO pin of the Electric Imp chip, which holds the ability to set the chip to wake from a sleeping condition, upon a rising edge on this pin. This functionality would be used to set the device to wake up upon light intensity changes that indicate a door opening of the refrigerator where it lies. To complete the dimensioning of the value of light intensity, traduced in the BJT's Base current value, which should be considered as enough to determine a door opening several tests were conducted. A particular BJT was fixed, hence fixing the

BJT's current amplification set by its value of β. The value of the pull-down resistor would then become the remaining variable, which would be used to dimension the circuit's light sensitivity. By replacing this resistor by a potentiometer several values of resistance were tested under the conditions of a refrigerator. This led to the introduction of a 500KΩ resistor, a high-valued resistor that would also set a small voltage drop around its terminals and with that guarantee that the circuit's output voltage would closely resemble the phototransistor's Collector voltage.

Figure 25 shows the schematic of the Light Sensing Circuit dimensioned.

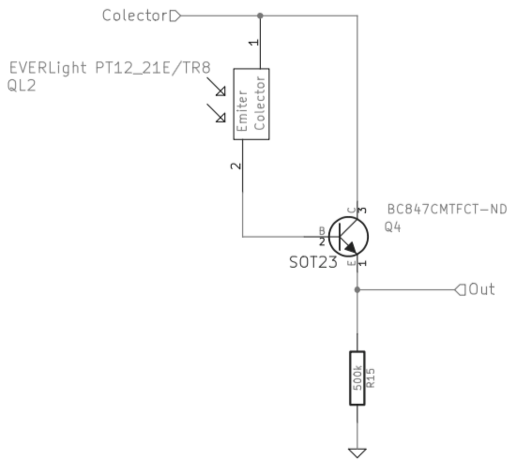



**Figure 25** **Schematic of the Light Sensing Circuit.**

The Buzzer Circuit simply introduces a piezo buzzer between a PWM configured pin of the Electric Imp chip and the ground reference voltage (refer to Figure 20). The PWM use means that two degrees of freedom are given to control the component – The signal's frequency and duty cycle. For this implementation, namely to control a piezo buzzer, a constant duty cycle would be set and it would be the signal's frequency that would be used to control the produced tone. This is justified by the component's core operation, as a piezo buzzer is a device composed by a material having piezoaelectric ability – The ability for a material to produce a voltage as it gets distorted and, the reverse, to get distorted as a voltage is applied at its terminals. Setting a voltage on and off across the device's terminals, at a certain frequency, would put the piezoelectric material to oscillate, hence creating the desired sound. The duty cycle would be set constant at 50% so that during a period the material would spend half of the time distorted an another half inactive, which would maximize the oscillation amplitude and consequently the sound volume level.

#### 3.1.1.3 Power Supply & Energy Consumption

Energy consumption is a common crossroad on IoT product development, particularly with applications that cannot use the electric grid, as wearables or mobile sensor networks. In one hand, high connectivity is required to achieve the purpose of having web-based services associated to the device. On the other hand, connectivity is a hungry feature for energy consumption and it should be minimized to allow extending the device's lifespan.

The following data presented was harvested by introducing an electrometer ahead of the EGGY board's power supply input, and validated with the use of a current probe at the same branch, connected to an oscilloscope.

Figure 26 shows the assembled circuit and its schematic.

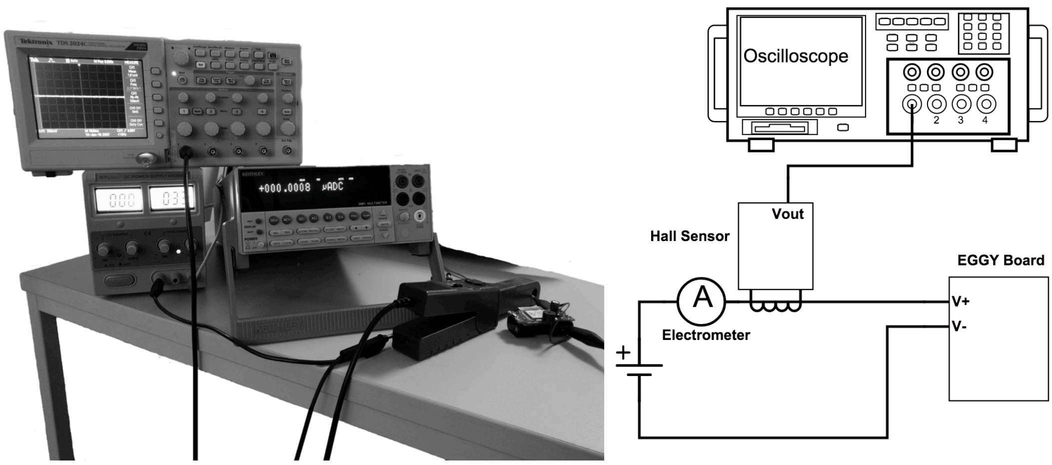



**Figure 26** **The device's current consumption testing circuit and its respective schematic.**

For this device four main statuses of consumption would be considered – Sleeping, Awake, Connecting and Connected.

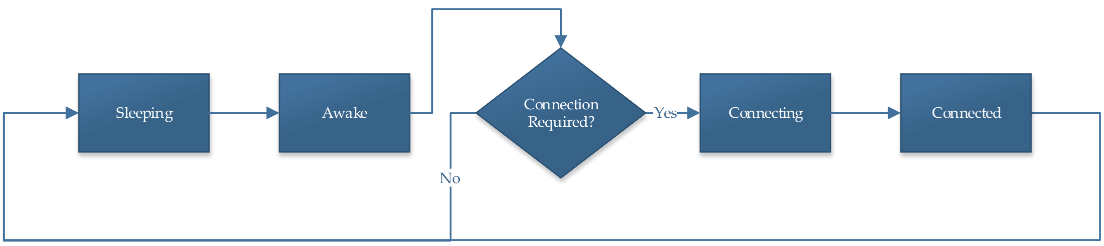



**Figure 27** **The several consumption statuses of the device.**

Booting refers to the moment in which the device is turned on. During a booting process the device tries to connect to a WiFi network. If it has gone through a BlinkUp[4] already it uses the network's credentials that it got from that process to complete the task. If no credentials were transmitted to the device yet, then no attempts to connect are made but the device maintains itself fully awaken, as a BlinkUp is expected. It is considered to be at the Awake status. Figure 28 shows the device's current consumption over time, while at this stage. An average steady current consumption of 37mA was observed. The one-second alternated levels are due to the lighting of indication LED at the bottom of the device.

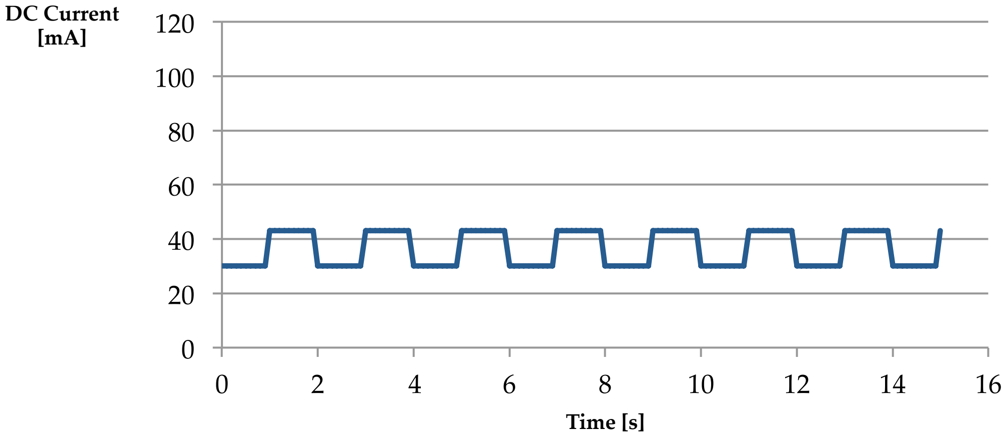



**Figure 28** **Illustration of the device's current consumption while fully awaken but offline.**

If the device is already aware of a network's credentials, then it periodically tries to connect to that network before abandoning that effort after sixty seconds. After this time the device would sleep for nine minutes before restarting the process. Figure 30 shows the current consumption while attempting and

[4] Optical configuration process, which uses light pulses from a screen of a smartphone or tablet to send the WiFi network's credentials to the device. This process is further detailed on section 3.1.2 of this Chapter.

failing to connect to a network. The peaks of 100mA correspond to the attempts to connect.

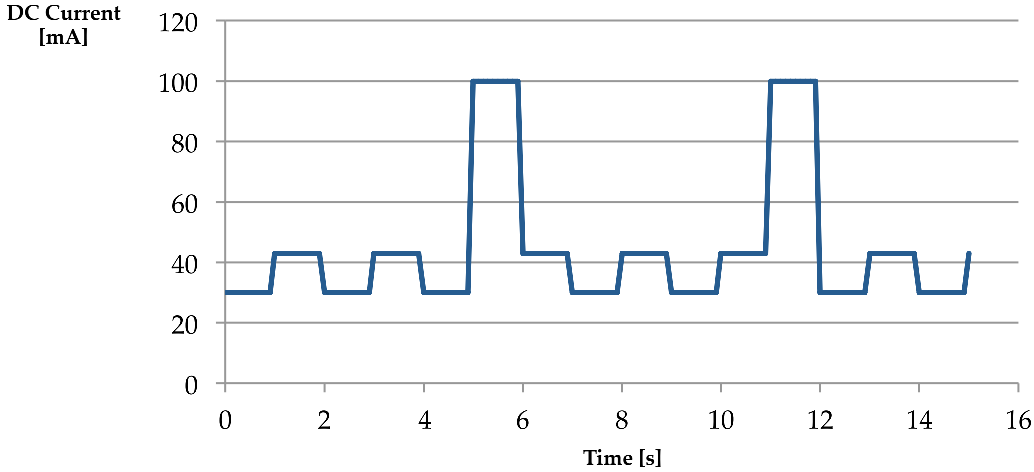



**Figure 29** **Illustration of the device's observed current consumption while connecting to a WiFi network.**

If the device is able to perform the connection then it status becomes Connected, and the current consumption of the device is dominated by the WiFi connectivity. The observed current consumption is shown in Figure 30, which is still characterized by two steady levels due to the indication LED lighting (On and Off) but now with a considerably higher mean value of 88mA.

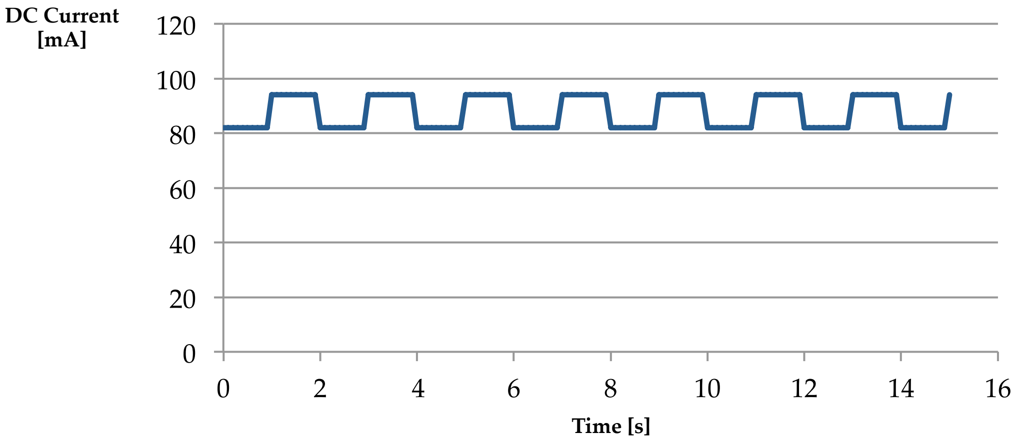



**Figure 30** **Illustration of the device's observed typical current consumption while online.**

During a booting process in which the device is already aware of a network's credentials the time spent at the Connected status can go up to 30 seconds, if no BlinkUp is performed during this period. If a BlinkUp occurs at the current booting process then this time reduces to 7 seconds.

After successfully connecting and sending booting-related data to its Agent (presented on chapter 3.2.1.2) the device falls into the Sleeping status. While at this status the device's steady current consumption observed was of 13µA.

Three events could take the device out of Sleeping – Being turned-off (sliding its power switch) for over a minute, a scheduled temperature sample or a fridge-door opening.

If the device is turned-off for less than a minute, then when it is turned back on it recovers its Sleeping status and proceeds normally until a next scheduled temperature sample or fridge-door opening. If this is not the case, then a Booting process would start over again immediately, and the current consumption is as depicted before for this status.

Temperature sampling periods are scheduled for every 15 minutes of an hour – These happen at hh:00, hh:15, hh:30 and hh:45. If the difference to the last temperature sample is smaller then 1°C then the device abstains from sending that reading to its Agent, whom would be responsible to store it at the online database, and so it does not connect to the WiFi network. The current consumption observed is depicted in Figure 31. An instant peak of 20µA was observed, corresponding to the sampling period.

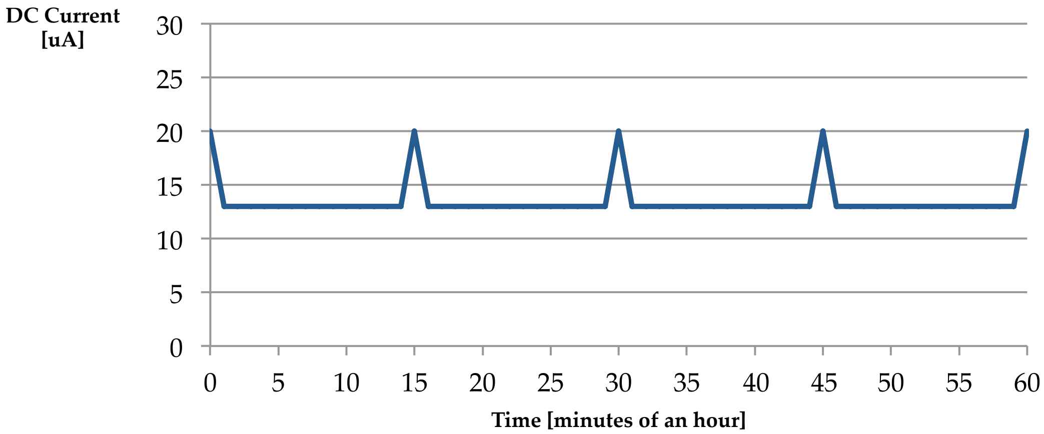



**Figure 31** **Illustration of the device's observed current consumption during an hour with no temperature changes (within one degree Celsius).**

If a relevant temperature change is observed then the device needs to turn its connectivity on and send the data via WiFi to its Agent. The current consumption while connecting is as previously illustrated in Figure 29 and Figure 30. The time spent at attempting to connect and at the Connected status depends on the connectivity conditions of the device, namely on how far it is from the access point, on the materials between them and on the electromagnetic interference verified. For further calculations this study considers this mean time to be 3 seconds, during which an average of 88mA of current is verified.

If the refrigerator door is opened, which is detected by the device's measuring phototransistor, the device immediately awakes. As this happens the device beeps a 2 second melody to remind the user of its presence, which is responsible for a steady 30mA current consumption during that period. After this the device falls into sleep and low-power awakes every second to check if the door is still opened. Figure 32 shows the observed current consumption while doing this sampling.

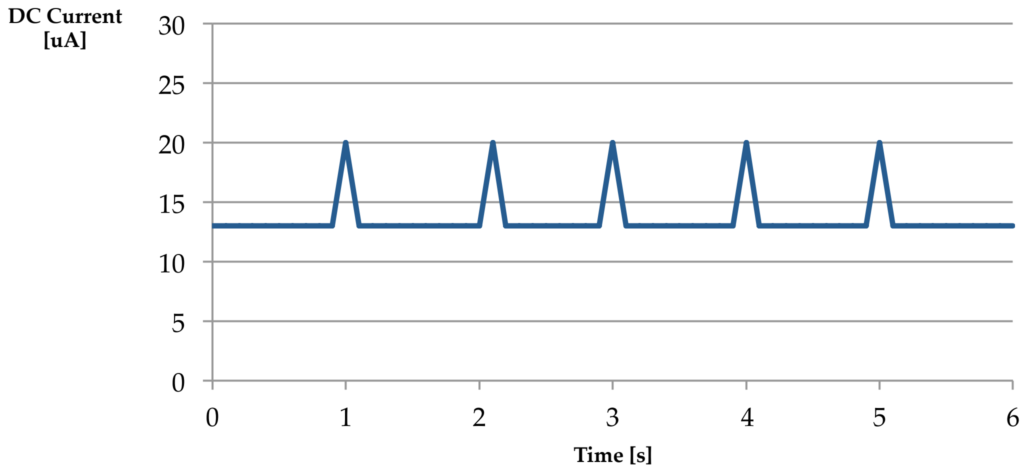



**Figure 32** **Illustration of the device's observed current consumption while sampling on door open.**

If the door is kept open for a determined period (set by the user's past behaviour) the device starts to beep a countdown every second during three seconds, after which it beeps a defeat song, if the door remains open. In total this can go up to 5 extra seconds of 30mA.

If the door is kept open for over 60 seconds the device considers this to be an alarm situation and reports this to its Agent, after connecting to the WiFi network. This process would then follow the connecting and connected consumption patterns described before.

As the door is closed the device attempts to connect and to send the data regarding the opening's timestamp and duration to its Agent. The current consumption while connecting is again as previously illustrated in Figure 29 and

Figure 30, and a mean time of 3 seconds to achieve the connection is again considered, during which an average of 88mA of current is being consumed.

Table 11 compiles the previously stated current consumption profiles in specific events. The Initial Booting refers to the time the EGGY is turned on by the user for the first time, and a BlinkUp is performed upon it. An Extra Booting is an unexpected event in which the EGGY accidentally reboots after an error. For these calculations it was considered that this event happens once per day. A Temperature Change happens when the device's sensor detect a temperature change of over 1°C at one of the device's four samples per hour. One change per hour was considered, resulting in twenty-four changes per day. A Short Door Opening considers a door opening for 5 seconds. It was considered that for the average user ten of these events happen per day. A Long Door Opening considers a door opening of 15 seconds, and five per day were considered. An Alarm Door Opening was considered for door an opening over 60 seconds, and one of these was considered to happen once per day. A Daily Connection happens at 0:00 and it corresponds to a daily update that the EGGY performs to guarantee that it is fully synched with the web platform and the user. The Base Operation states the base consumption over which the contribution of the above events should be summed.

**Table 11** **The device's average current consumption for a list of events.**

| N | Event | Average Current Consumption $I_{avg}$[mA] | Average Duration $\Delta t_{avg}$[s] | Average Frequency per Day $f$ |
|---|---|---|---|---|
| **0** | **Initial Booting** | 88 | 7 | - |
| **1** | **Extra Booting** | 88 | 30 | 1 |
| **2** | **Temperature Change** | 88 | 5 | 24 |
| **3** | **Short Door Opening** | 63 | 10 | 10 |
| **4** | **Long Door Opening** | 50 | 20 | 5 |
| **5** | **Alarm Door Opening** | 41 | 60 | 1 |
| **6** | **Daily Connection** | 88 | 5 | 1 |
| **7** | **Base Operation per Hour** | 0.015 | 3600 | 24 |

The underlying electric charge drawn to the device would then be calculated by summing the addition of the several events over the base operation contribution. To comply with the batteries' standard metric for charge capacity, this calculation would be presented in mAh.

$$E_{daily} = \frac{I_{avg}[0] \cdot \Delta t_{avg}[0]}{3600} + \sum_{1}^{N} \frac{I_{avg}[N] \cdot \Delta t_{avg}[N] \cdot f[N]}{3600} \quad [mAh]$$

**Equation 2** **Calculus of the device's daily charge drawn.**

$$E_{yearly} = \frac{I_{avg}[0] \cdot \Delta t_{avg}[0]}{3600} + \sum_{1}^{N} \frac{I_{avg}[N] \cdot \Delta t_{avg}[N] \cdot f[N]}{3600} * 365 \quad [mAh]$$

**Equation 3** **Calculus of the device's yearly charge drawn.**

For the given values of Table 11 this calculation resulted in the following values,

$$E_{daily} = 8{,}14 \quad [mAh]$$

$$E_{yearly} = 2909{,}63 \quad [mAh]$$

Based on this consumption profile, the decision for the device's power source relied in using two AA lithium batteries, which combined, under the typical conditions of a household, would deliver roughly 6000mAh of charge capacity – Enough for two years of operation of the device, according to the calculations presented before. Figure 33 shows the effect of temperature on the chosen batteries' capacity. It is noticed a slight decrease on the capacity as the temperature gets close to 5°C, around which the temperature inside a refrigerator is expected to range, regarding its peak at 20°C, but the 3000mAh minimum threshold is never surpassed.

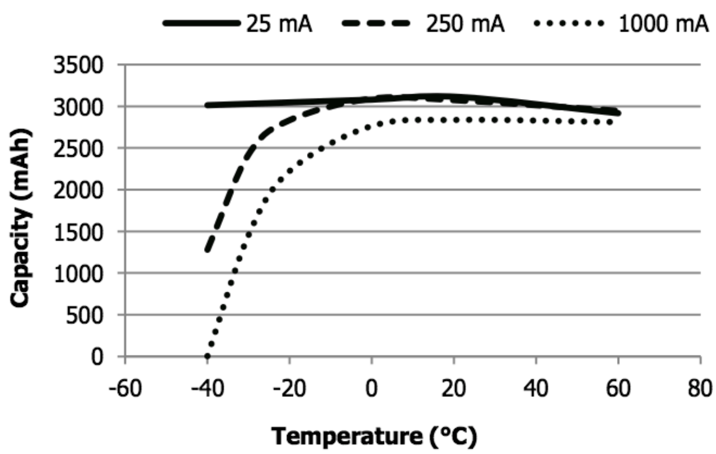
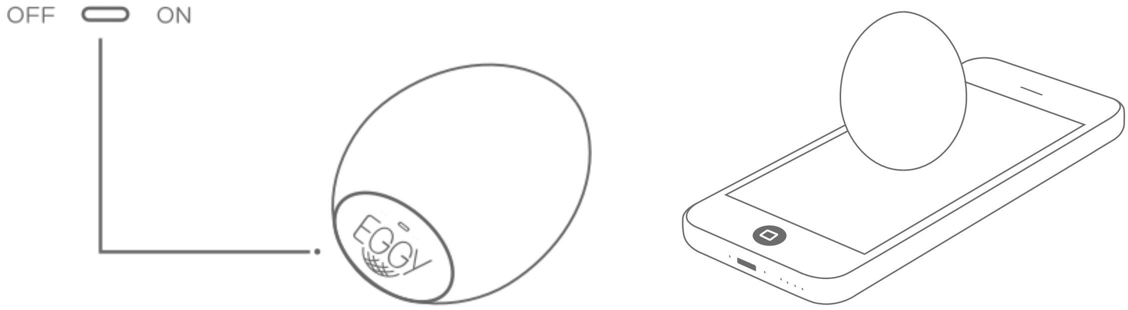



**Figure 33** **The temperature effect on the chosen batteries' charge capacity.**

### 3.1.2 BlinkUp

After being assembled it would be necessary to have a means of communicating with the device. Using its WiFi connectivity would not be an option, since prior to that some kind of communication between the user and the device would have to have happened already, as the device would need the credentials of the WiFi network it should connect to in order to complete that task. So an alternative, offline type of communication was needed, primarily to complete the task of putting the device online, after which the communication could definitely turn to the Internet.

To simplify the process of telling the device just a few bytes corresponding to a couple of strings, namely the SSID and respective password of the WiFi network it should connect to, instead of using a common cable-based solution, as a USB connection to a screen-featured computing device, the Electric Imp platform provides a technology called BlinkUp. This technology takes property of two of the hardware I/O ports, to which it assigns a bi-colour LED and a phototransistor. The phototransistor gives the device the capability to detect light intensity changes, which would be used as a way to code and transmit the information required. An API to encode these strings into light pulses would be distributed by the Electric Imp, which would be later assigned to iOS and Android mobile applications that would put the smartphone's screen to blink according to the information being transmitted. The bi-colour LED would grant the user a way to acknowledge the status of the device, and the success of the BlinkUp process after its completion. Figure 34 illustrates the BlinkUp process.




(1) (2)

**Figure 34** **Illustration of the BlinkUp process.**

### 3.1.3 Blessing

During its lifespan the device would undergo several statuses. The first status would be called Assembled, and it corresponds to the moment after all the hardware pieces have been successfully assembled and no software is still being run. Before it starts to do so it is necessary to guarantee that all the hardware is functioning according to the specifications. A set of tests over the hardware is run and after that, in the case of success, the device connects to the Electric Imp servers and downloads its operation mode firmware. This process is called Blessing. After being Blessed the device would be ready to leave the factory for distribution among the users. This new status would be called Newborn.

To achieve the Blessing an additional device would have to be developed, called the Blesser – A simple device composed by an Electric Imp chip, encapsulated on an SD card configuration, a breakout board to easily access the Electric Imp pins, a LED, a button and an auxiliary circuit. This device would be used to do the BlinkUp on the newly Assembled EGGYs, by aligning the Blesser blinking LED with the EGGY's phototransistor. The Blesser board's Electric Imp chip would be set as a special one, specially dedicated to a Blesser board, and the BlinkUp over it would tell the newly Assembled EGGY that a Blessing process was starting. With this, the EGGY would download the hardware testing code, validate the hardware and in the case of success Bless itself – It would be ready for distribution. Figure 35 shows the Blesser board assembled and its schematic.

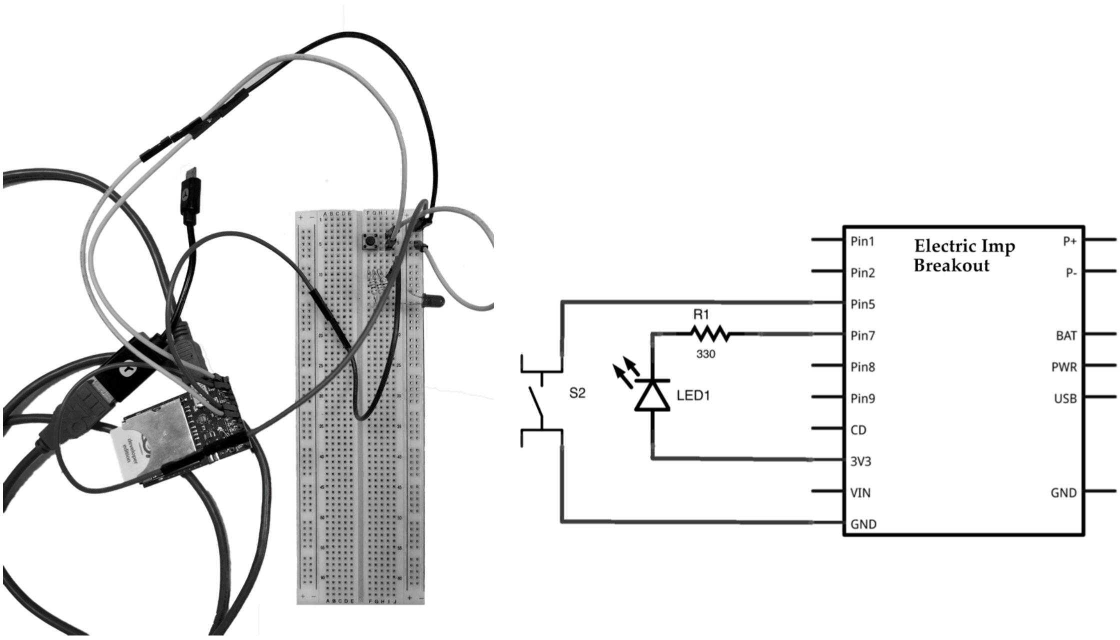



**Figure 35** **The Blesser board – Picture (left) and schematic (right).**

To consider the hardware as validated the device would need to check the temperature and light intensity values and their variations over time, as well as to activate the buzzer so that the operator could validate that a sound is being produced and evaluate the progress on the testing procedure. Figure 36 illustrates the hardware validation algorithm.

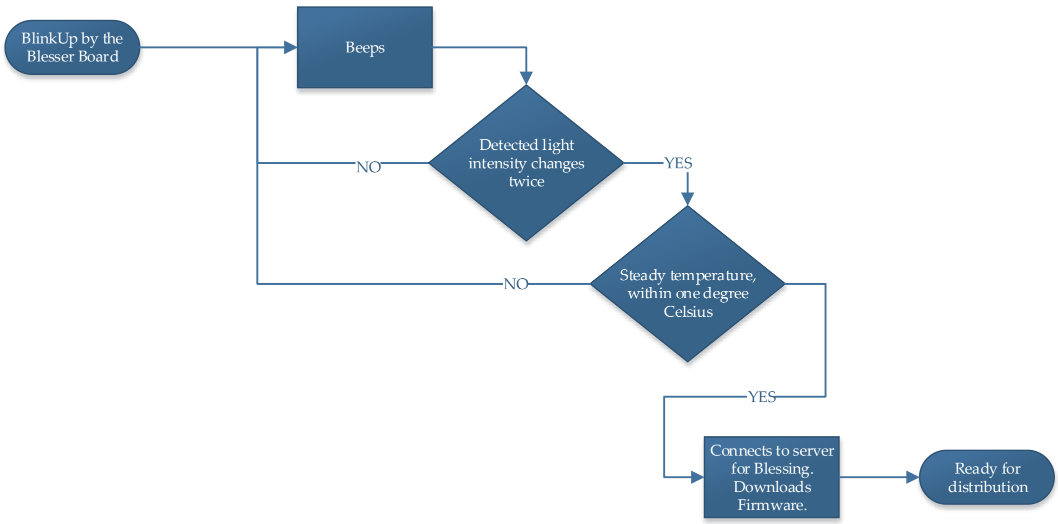



**Figure 36** **Hardware validation algorithm diagram.**

The Blessing process would allow a quicker validation and setup of the hardware by almost fully automatizing it.  Figure 37 illustrates the steps of the Blessing process.

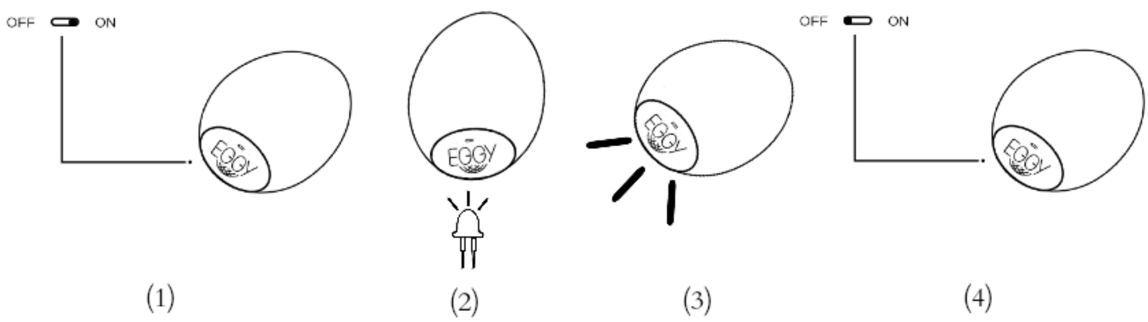



**Figure 37** **Illustration of the Blessing process steps.**

### 3.1.4 Operation Algorithm

After getting the status of Blessed the device would be ready to start its normal operation mode. In addition to the Assembled and Blessed/Newborn statuses already stated, the device would now be ready to undergo four other – Active, Inactive, Nest Quest and Vacations. Figure 38 relates all these statuses in a diagram.

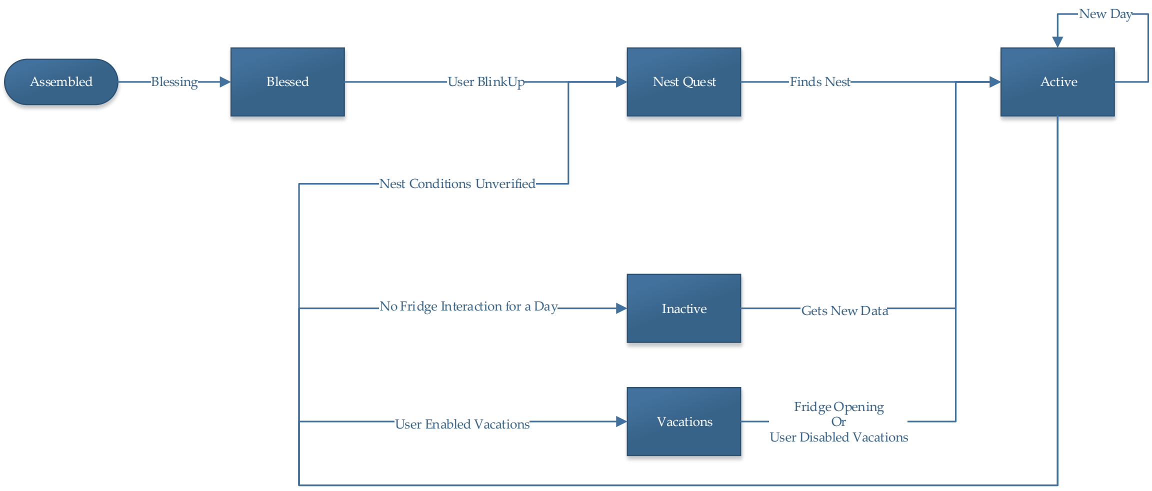



**Figure 38** **Diagram of the six EGGY statuses.**

#### 1. Newborn

After leaving the factory as a Newborn EGGY the device would be ready to follow the BlinkUp process by its new user. After being turned on, the device would hold for thirty seconds before it would start to run its standard code. During that period the device would be actively checking the light intensity variations and ready to start a new BlinkUp process at any moment. After that time, the device would fall asleep as a way to preserve battery – To guarantee that if it was left forgotten on this state the battery wouldn't be totally consumed in a short period. To get the EGGY awaken the user would have to turn it off, hold for a minute, and turn it on again. This heavy consumption during this pre-BlinkUp period happens because the device needs to be WiFi connected and fully awaken during it. More about the device's energy consumption patterns can be found on chapter 3.1.1.3 of this document.

2. **Nest Quest**

After getting the WiFi credentials of the user's home network from the BlinkUp procedure, the device would register itself at the web application database, associate itself to the user's Family and set its status to Nest Quest. While in this status the device would be scanning its surrounding environment with the help of its sensors and understanding if the conditions correspond to any of the pre-determined applications, called Nests, considered for the device. For this work only one Nest would be considered – The refrigerator.

The validation of these conditions would be done with intervals of fifteen minutes, again as a way for the device rationalize its own energy consumption. This value was considered adequate based on these conditions variations' typical time constants.

For the refrigerator application what would be under validation is the light intensity and temperature variations. It would be necessary to identify a decrease of temperature until values that were considered to be adequate for a refrigerator, namely equal or lower than 10°C, and at the same time detected absence of light. If these conditions would be verified, the device would evolve into its Active status.

Figure 39 illustrates the Nest Quest process for the refrigerator's case.

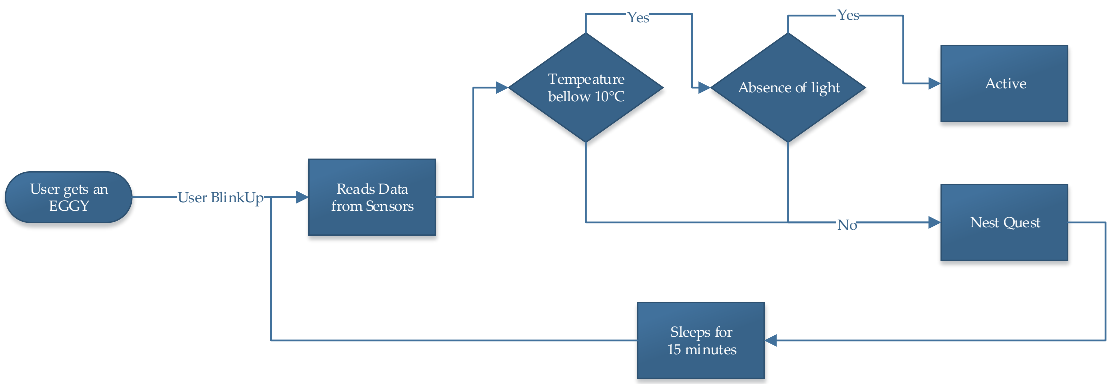



**Figure 39** **Diagram of the Nest Quest process.**

Each Nesting conditions come with the opposing UnNesting conditions. For the device to consider itself out of this Nest, the default condition to be verified is the temperature above 12°C. Losing a Nest brings the device back to its Nest Quest status, and Nest conditions should be verified again in order to reinstate the Active status.

**3. Active**

The Active status follows the Nest Quest. This is the main status of the device, in which its standard operation occurs.

At this status the device would have to periodically connect to the web platform, through the device's Agent[5]. The heterogeneous property of the messages' type and content that would have to be shared between these entities made imperious the development of a protocol upon which to set the communication between them.

A basic and uniform structure for the messages exchanged would have to be settled. The decision relied on the simplest implementation, characterized by four mandatory fields, denominated Headers, Label, Timestamp and Data. The Label and Timestamp fields would have imposed variable types – The Label field would expect a String format – a linguistic word, and the Timestamp field a UNIX timestamp, a single signed Integer number representing a date. In another hand, the Data field format would be left with a higher degree of freedom, as different message purposes might need different kinds of data to be shared. Any serializable data, as a Table, Array, String, Integer, Float or Boolean, could be used to fill this field. The Headers field would stand in the middle to what format rigour is concerned. The Headers field is packed with data regarding the device's operation – Internal variables that by being shared on every message guarantee the correct execution of the protocol and the synching between the device at its Agent, and allow corrections if any defect is detected. For the current implementation two variables in the Headers field are shared – Corresponding to the device's Nest and the number of connections failed before the establishment of the current connection, which allowed the exchange of the

[5] Piece of software residing in the cloud responsible to communicate with the device and to represent it towards the rest of the web platform, including the database. More about the device's Agent can be found on the Chapter 3.2 of this document.

given message. But other Headers field variables could be added indiscriminately when needed. Figure 40 illustrates this structure.

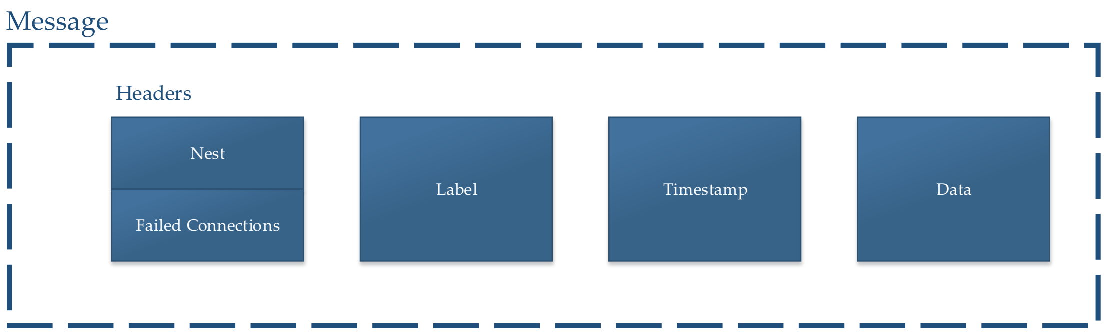



**Figure 40** **The device's messages' basic structure.**

Two types of queries from the device were then defined, and would constitute a communication protocol for the device that would be called EGGTTP – These queries could be of the type SEND or the type ASK, similarly to the widely popular POST and GET, respectively, of the HTTP protocol. The SEND query tells the device's Agent that the device's intention is solely to share data and that no reply is expected. Opposingly, the ASK query tells the Agent that an answer is expected, which should be processed according to the message's content, namely its Label variable.

While in the Active status the device has a common main behaviour for every awakening, independently of the event that triggered it or even the actual Nest. This can be deconstructed into three blocks – The Check block, which divides itself into Check Nest, Check Time and Check Data, the Action block and the Connect block. To guarantee a prolonged energetic autonomy of the device, and considering the typical time constant of the data under scope to ensure that no relevant information is lost in between, a sleeping period is established between periodic awakenings. For the case of a refrigerator as the Nest, in which the data being considered for this constraint is related to temperature readings, this sampling was determined to occur four times per hour, at hh:00, hh:15, hh:30 and hh:45. Figure 41 illustrates this behaviour.

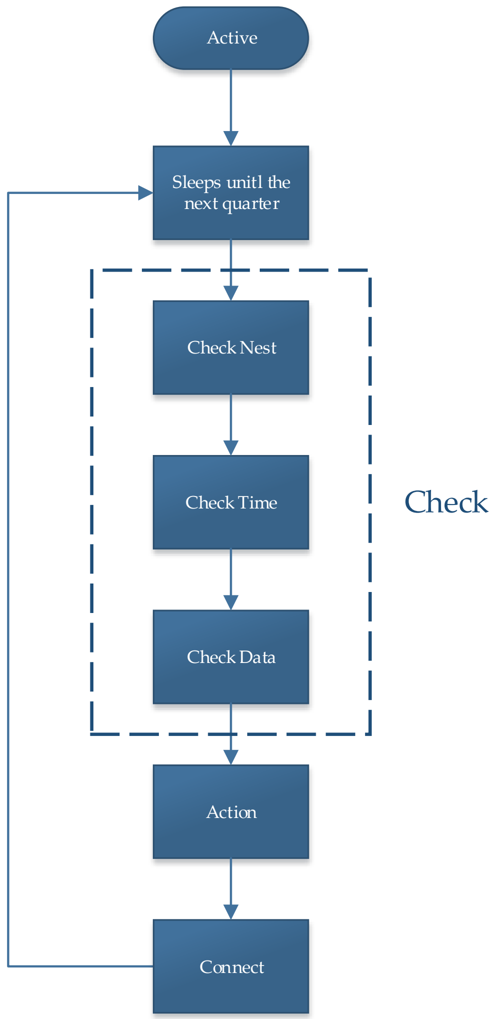



**Figure 41** **Diagram of the device's main operation on awakening.**

During the progress of the device's operation, on every awakening, a buffer with each element composed by a message and its respective query type would be formed. At the end of each awakening the device would check if the buffer has been filled during that awakening, and if that would turn to be the case, it would start a connection to its Agent and iteratively take each one of these entries from the buffer and perform the sending of the respective message using the type of query to which it was assigned – This would happen on the Connect block. More about this operation block is described further ahead in this section.

The first operation block to be performed is the one called Check, composed by the Check Nest, Check Time and Check Data routines.

As it wakes up the device needs to guarantee that its Nest was kept the same. The Check Nest block operates to ensure exactly this. If a Nest change is acknowledged, the device appends a new entry regarding this change to the messages' buffer and proceeds to the next block. More about this process is described further ahead in this section, as the several ways to get the device out of its Active status are presented.

After the validation of the Nest the device also needs to check the time and verify is any time triggered event is to happen, as a New Day event which guarantees that the device connects to the web at least once per day, and during which some data is exchanged between the device and the Agent to guarantee that they are fully synched. To trigger this exchange, the device adds an entry to the messages buffer with a label to be interpreted as a New Day event an the necessary data to complete this goal, and proceeds to the next block.

The following Check Data block corresponds to the device's main purpose – To collect data from its sensors and process it according to its Nest. As it gets to this block, the first task that the device performs is a screening to understand what motivated the awakening – For the case of a refrigerator as Nest, the device would validate if it was reaching one of the four temperature sampling periods per hour or a door opening related event that motivated the awakening, and in that case, it would proceed with the operations. If the awakening was due to another reason, the device would ignore the processing of the sensors' readings. But on any of these cases, after this screening the device would check if there were still entries at the messages' buffer and if that would be the case it would add an extra entry, of the type ASK, to that buffer, with a message labelled Regular Update, before finally moving into Action. The device uses this message to ask its Agent about any updates, required by the user or automatically set by the web platform, related to the device's configuration. The actual implementation takes use of this tool to tell the device if it should beep according to its operation or if the user triggered the Silent Mode[6], and to update the device about the user's achievements and goals for it to acknowledge if there were changes related to which level of behaviour should be granted with a victory melody and which should be warned with a defeat one.

Figure 42 illustrates this main procedure for the refrigerator case.

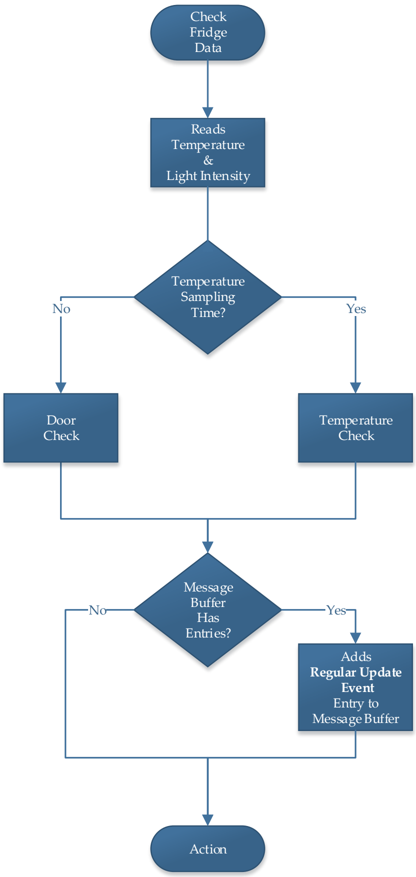



**Figure 42** **Check Data block main operation, for the case of a refrigerator as Nest.**

[6] Configuration of the device which allows the user to decide about the device's beeping. If the Silent Mode is set, the device abstains itself from beeping on any occasion.

If the device acknowledges that it was reaching one of the four temperature sampling periods per hour that motivated the awakening then it moves into the Temperature Check procedure. Here the device will compare the current temperature reading with the last one shared with the device's Agent. If a temperature change, positive or negative, larger than 1°C is detected than the device prepares to share the new value with its Agent, and updates its data internally to register the current temperature value as the last update, as this value becomes the new baseline upon which another temperature change of 1°C will generate the next update. A new entry to the messages' buffer carrying a message labelled as Temperature Event is then added, as a temperature change is detected. Independently of the temperature change update, if the device detects that the temperature has gone through pre-established thresholds then it creates another message labelled as Temperature Alarm which is also added to the messages' buffer, and that will trigger an alarm message being sent to the user afterwards, acknowledging the abnormal temperature for a refrigerator. The current implementation establishes this to be triggered when the temperature rises over 11°C.

Figure 43 illustrates the Temperature Check procedure.

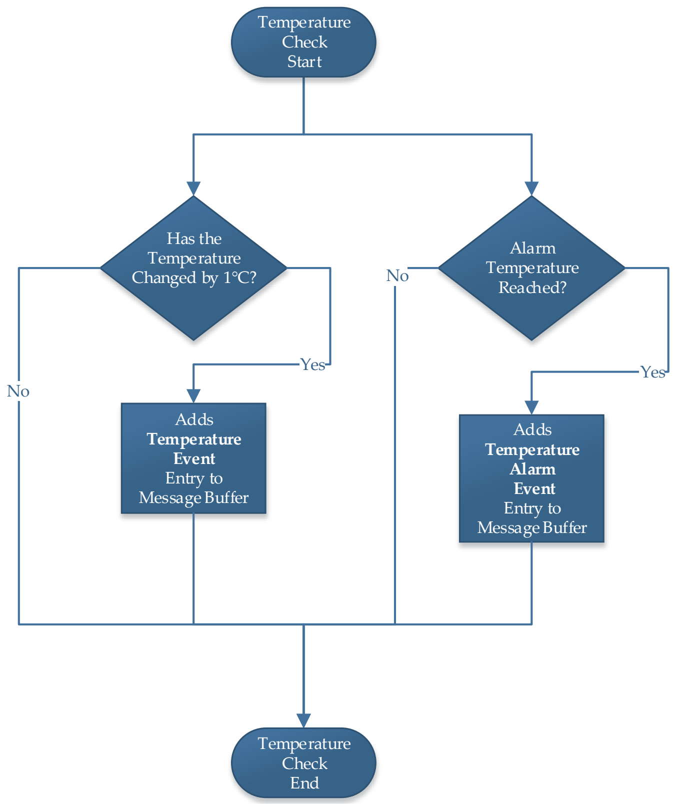



**Figure 43** **The Temperature Check procedure.**

If the device acknowledges that the awakening was not motivated by a temperature sampling period then it moves into understanding if it has happened due to any door-related event. Two door-monitoring statuses were defined – Opened and Closed, which relate to how the device perceives the refrigerator door to be opened or closed, respectively.

As it wakes up the device starts by testing if the door has just been opened, this is, if the light intensity read from its respective sensor indicates that the door is opened and its door-monitoring status is currently set to Closed. If this turns to be the case, the device defines its door-monitoring status to be Opened, which leads to a slight change in behaviour by the device – The device now sets a sleeping period of two seconds and turns off the automatic awakening on light detection. It saves the information about the new status internally and sets the door opening melody to be played at the following Action block.

If the device is waking up with its door-monitoring status already set to Opened then the device checks for how long has the door been opened for and how close it is from the door-closing time limit established by the web platform upon learning from the user's past behaviour. By default, this time is 15 seconds. If the device is waking up on door opened and the limit is less than 5 seconds away then the device sets a three-time single beep countdown that tells the user how close it is from surpassing this limit. If the duration of the door opening is currently above the 5 seconds away from this limit no beep is set to be played. If it has just gone over the limit, a defeat melody is set to be played. After setting the beeping according to the door opening duration, the device checks if the alarm duration has been surpassed, which by default is set as 60 seconds. If it has, the device introduces a new entry to the messages' buffer, characterized by a message labelled as Door Opened Alarm. The sharing of this message with the device's Agent will later trigger a message to be sent to the user, acknowledging the abnormal duration of a door opening event.

If upon the awakening the device reads absence of light from its sensor and the door-monitoring status is set to Opened it understands that the refrigerator door has just been closed. With this the device sets back the light sensing awakening and the following sleep period to be until the next temperature sampling quarter of an hour. It sets the melody to be played, a victory one if the time limit for the opening was not surpassed, or a generic one just to signal the closing, if it was. The device then compiles the information regarding the opening into a new message, which contains the timestamp of the door opening and its duration, and creates a new entry at the messages' buffer which is filled with this message.

Figure 44 illustrates the Door Check procedure.

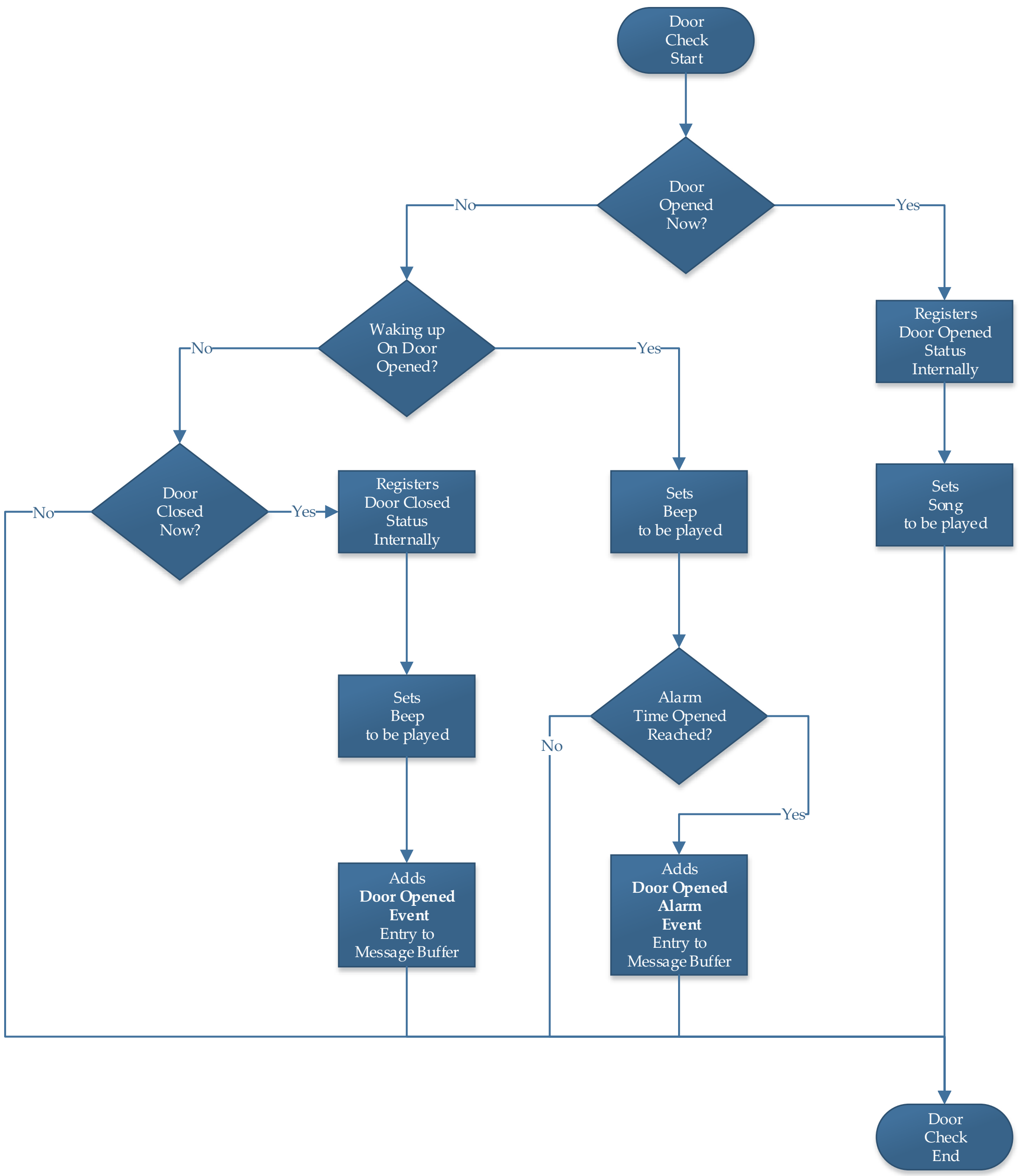



**Figure 44** **The Door Check procedure.**

There are three ways for the device to get out of its Active status – By being set into Vacations, by becoming Inactive and by losing its Nest. The case of Nest losing was already presented in the previous section of this chapter, regarding the Nest Quest status. Follows a description of the Inactive and Vacations cases.

**4. Inactive**

The device turns to its Inactive status when no connection is received for a day. The web platform acknowledges that the EGGY was turned-off, that its battery ran off or that the device was put in a place of no connectivity. No changes in the device's operation mode occur though. If the device manages to connect to a network and the web platform receives data from it then the device's status is set back to Active.

**5. Vacations**

The user is given the opportunity to declare that it is going to be away and to put its EGGY into a self-dominated Vacations status. No significant changes occur in the device's procedure while in this status, as the impact relies primarily in the way data is processed on the web platform side. Opening the refrigerator door while at this status would bring the device back to Active, as it would changing the device settings back to this status using the User App of the Web Platform.

## 3.2 The Web Platform

### 3.2.1 Structure

The IoT is known to bring together very heterogeneous environments in which a lot of distributed-computing needs to happen, as each of the system's elements lives on its own setting and is granted with its own very specific role. There were specified five elements – The *Device*, the *Agent*, the *Database*, the *Web Application* and the *User Application*.

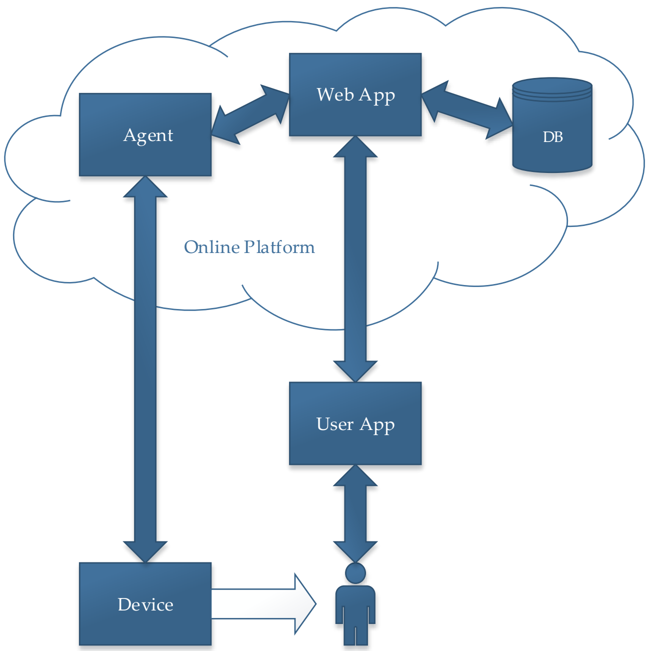



**Figure 45 The Web Platform entities and their basic relationships.**

The device was already given the deserved focus on the previous chapter, in which the messages' format and the communication moments were presented and justified. Now follows a description of what happens at the other end, as this information being shared by the device hits its Agent.

#### 3.2.1.1 Agent

The Agent is a piece of software, residing at the servers of the Electric Imp, associated to a single device. It was developed to become the entity responsible to represent the device at the web platform's context – It bridges the device with the Database and the Web App. It also manages and monitors the device's operation.

The Agent has its first appearance on an EGGY's lifecycle at its very beginning, right after a successful BlinkUp of the device by the user – The moment in which the user, through the User Application, activates the EGGY to become fully functional and connected to its domestic WiFi network (refer to the section 3.2.1 of this Chapter for more detail on the BlinkUp process). After setting the device to successfully connect to the WiFi network, the User Application calls the Web App, which does some processing on the EGGY's registration data and contacts the EGGY's Agent to finally validate its registration process and login itself at the Web Platform. Figure 46 shows the evolution of the Login process through the several entities of the Web Platform.

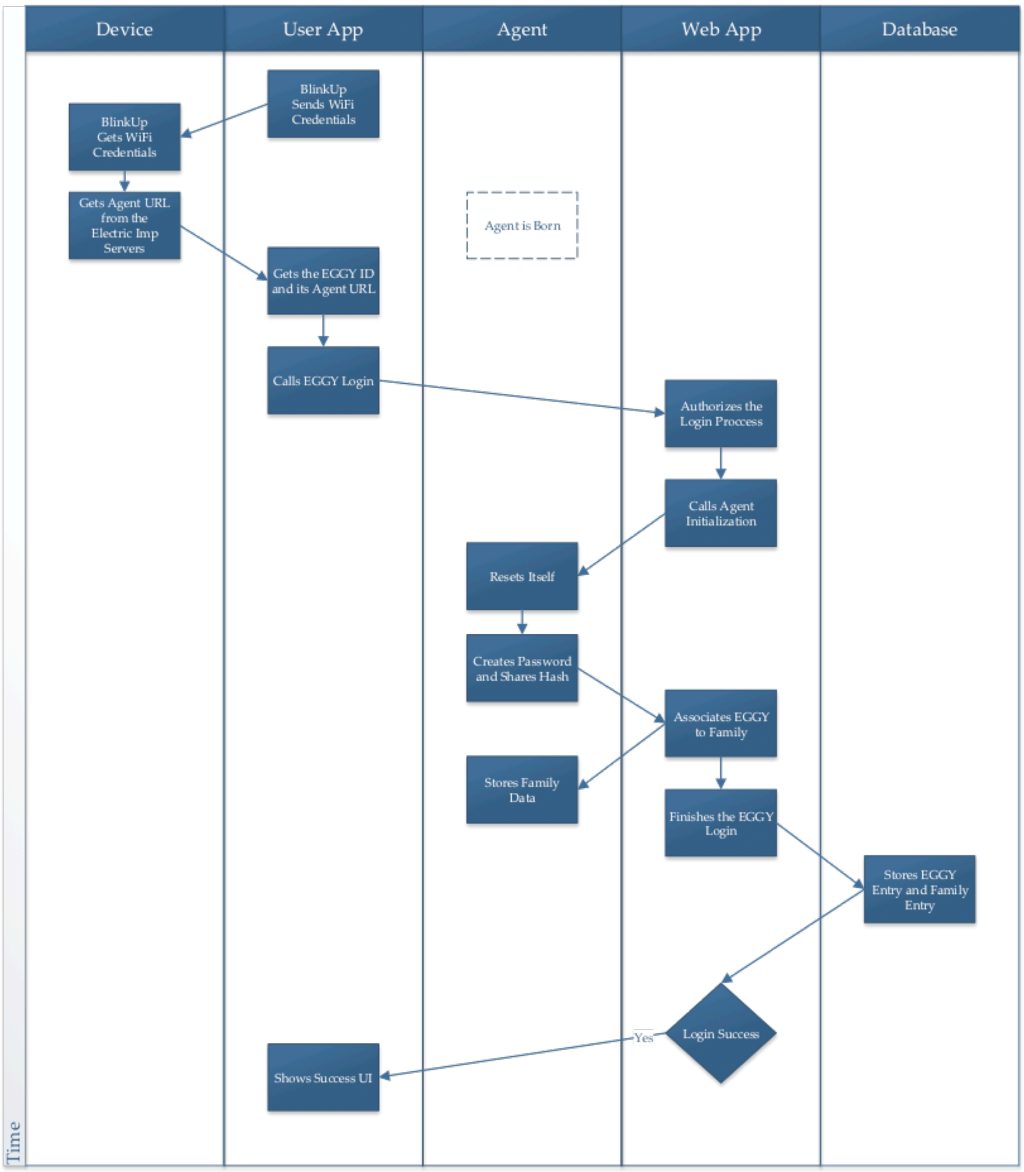



**Figure 46** **Time-based diagram of the EGGY Login process through the several Web Platform entities.**

The Agent is pre-set with a list HTTP queries that it will answer. One of these queries relates to the EGGY Login procedure. During this procedure the first task performed by the Agent is the cleansing of its own global variables and the creation of a new table to hold them. These variables correspond to the main, non-volatile data that the Agent needs to store in order to perform every task that it is expected to perform. Table 12 shows the list of these variables and links each one to its default value and to a short description of the data that each represents.

**Table 12** **The EGGY's Agent Global variables.**

| Variable name | Format | Short Description |
|---|---|---|
| **eggyID** | String | Identifies a specific EGGY device;<br>Default value: "Unknown"; |
| **eggyPass** | String | Password associated to the EGGY Login, performed by its Agent;<br>Default value: "Undefined"; |
| **eggyNest** | String | Identifies the environment in which the EGGY is operating<br>(e.g. "Fridge");<br>Default value: "None"; |
| **eggyStatus** | String | Describes the status of the EGGY (between "Active", "Inactive", "Vacations", "NestQuest "and "Newborn");<br>Default value: "Newborn"; |
| **eggyLastUpdate** | Integer | UNIX timestamp which identifies the last time that the device was updated; Default value: 0; |
| **eggyLastAlarm** | Table | Stores the alarms status ("on"/"off") and respective timestamps on a Table format; |
| **eggyNv** | Table | Stores the device's NVRAM data;<br>Default value: Null; |
| **agentURL** | String | Holds the Agent's unique URL on a String format<br>Default value: (Self Agent URL)<br>(e.g. "https://agent.electricimp.com/123456789"); |
| **agentResetCall** | Boolean | Variable used to control remote calls to reset the Agent;<br>Default value: false; |
| **settingMaxOpenTime** | Integer | Maximum time to be considered as a positive achievement by the EGGY;<br>Default value: 15; |
| **settingSound** | Boolean | Sound setting of the device, set as Boolean;<br>Default value: false; |
| **familyData** | Table | Family data of the Agent's EGGY, as stored at the Database;<br>Default value: null; |

Following the reset of these variables, the Agent proceeds with the Login at the Web Platform of its given EGGY. To achieve this a password would be created and stored by the Agent prior to being hashed and shared via an HTTP Header with the Web Application, which would finally complete the Login process and set the hash to be stored at the Database, as depicted on Figure 46.

As a device successfully logs in into the Web Platform, meaning that it is properly registered and authenticated and that all the participating entities are aware of its existence, the device starts with its normal operation which, in the point of view of the Web Platform, consists in periodically sending data through two types of queries, called SEND and ASK (please refer to the section 3.1.4 of this chapter for more detail on the messages' structure) that define what was called the EGGTTP communication protocol. The Agent is the Web Platform's entity responsible to listen to the device's messages, to process them and to act on them. The other type of queries that the Agent responds to are HTTP type ones, as the Login query already depicted, with the difference that these do not come from the device, but from the rest of the connected entities of the Web Platform. Follows a description of the several types of query and query content answered by the Agent.

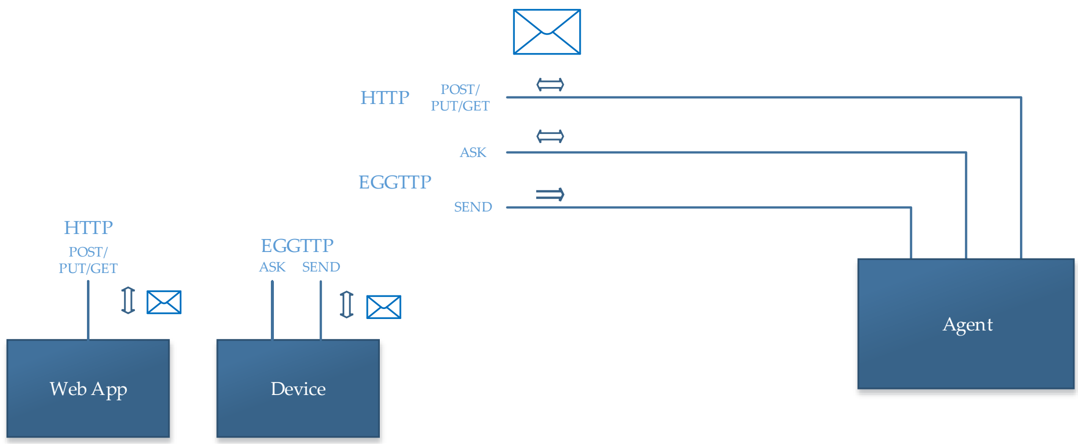



**Figure 47** **Illustration of the EGGY Agent's message exchange channels.**

## ASK Channel

The EGGTTP protocol ASK queries tell the Agent that the device expects an answer from this call.

**Booting Query**

Every time that the device, through its microprocessor, boots – because the power supply was switched on or because of a specific event, as a code error or a firmware update, triggered it – the device sends an ASK query to its Agent labelled as *BootingEvent*.

The message gets to the device's Agent filled with the EGGY ID, the device's unique identifier, which the Agent stores if no EGGY ID was known by then.

With the EGGY ID the Agent queries the Web App, which in its turn will forward the request to the Database, to retrieve some information regarding the EGGY, namely its current status. Every booting event is to put the status as Nest Quest (please refer to the device's statuses debated on section 3.1 of this chapter) independently of the current status. This is because a booting is related to the reset of the device and, as so, there would be the need for the device to understand its current environment and guarantee that it is ready to restart its normal operation – associated to its Active status. So the Agent analysis the current status of the device and if it is different from Nest Quest it sends a call to the Web App, which will again forward it to the Database, to change the EGGY status to the Nest Quest value.

The Agent also retrieves some information about the device's configuration from the Database, as the current Sound Setting, which sets the device to beep or to be silent, and the Max Time Setting, which defines the acceptable duration of a door opening for this to be considered as a positive behaviour. If none are set at the Database, the Agent then uses the default values it has stored internally. This device's configuration data is the answer that the device is expecting from this ASK query. The Agent then packs this information into a new message and replies it to the device.

**New Day Query**

This ASK query is sent by the device every day, by 00:00 local time. This happens to ensure that, at least on a daily basis, the device gets its configuration variables updated – the Sound Setting and the Max Time Setting. As the Agent gets this call it checks the Sound Setting and processes the new Max Time Setting. The former task demands having information about the user's last behaviours, as the new value is to be computed according to the user's improvement curve. After determining this value, the Agent packs the configuration variables into a new message and replies it to the device.

#### Regular Update Query

A Regular Update ASK query is sent from the device every time that it has another reason to connect and none is related to another ASK query. This happens to guarantee that changes in configuration variables that require (close to) immediate changes in the device's operation are known by the device as soon as possible. Currently the configuration variable that has this characteristic is the Sound Setting. The user expects to have the behaviour of its EGGY changed close to the moment in which it set the device to beep at will or to be silent (setting *on* or *off* the sound from the device, respectively). So every time that the device has something to share with the Agent and the device's energy consumption increased price to pay (related to the WiFi connectivity) is already assumed the device adds an extra ASK query to the connection's messages' buffer, labelled as a Regular Update, which is then forwarded to the Agent. After getting the current configuration variables, the Agent packs them into a new message and replies it to the device.

### SEND Channel

The EGGTTP protocol SEND queries tell the Agent that the device is not expecting any answer from this call.

#### WiFi Report Query

Every time that the device is set to connect to any the WiFi network, while at its Active status, it adds a SEND query entry to the messages' buffer labelled as *WiFiReportEvent*. This message is packed with data related to the device's connectivity quality, namely the Received Signal Strenght Indication (RSSI), measured in dBm, before being sent to the Agent. As the Agent receives this message it simply calls the Web App to store this data, which, in its turn, will contact the Database to do so.

**Battery Report Query**

As with the WiFi Report, a Battery Report is also programmed to be shared with the Agent, in the form of a SEND query, every time that the device is set to connect because of another reason – another ASK or SEND query. The device packs this message with a reading of the supply voltage, which could then be used to determine the charge status of the device's batteries. As with the WiFi Report, as the Agent receives this message it simply calls the Web App to store this data, which, in its turn, will contact the Database to do so.

**New Nest Query**

When the EGGY detects a new Nest – a monitoring environment as, for example, a refrigerator – it sends this information to its Agent in the form of a SEND query. As the Agent receives this data it starts by analysing the device's current status, namely to check if it is on Nest Quest, and evaluating if the new data coming from the device really sets a new Nest. If any of these conditions turns to be verified then the Agent moves into processing this call, and it starts to do so by storing the new Nest locally and by calling the Web App, which in its turn will call the Database, to store the new Nest. After completing this, the Agent would also check if the new Nest is not the absence of Nest, labelled as "None". If this is not the case and the new Nest is an actual monitoring environment then the Agent would also force the EGGY status to become Active if it was not before. It then stores the new Active status locally and calls the Web App, which once again would contact the Database, to store and secure this new information.

**Door Opening Report Query**

A Door Opening Report is sent by the device in the form of a SEND query when the refrigerator door was closed after being open for a certain amount of time. As the message is received the Agent checks if a door open alarm was occurring and if that is the case it turns off the alarm signal, by setting the corresponding internal variable of the Last Alarms table to *off*. The Agent then checks the device's current status and guarantees that it is not Nest Quest in order to proceed with the processing of the data shared. If the device's status is Active, then the Agent sends the door opening data, composed by the timestamp of the opening and its duration, to the Web App, which will later forward it to the Database where it is stored.

**Door Opening Alarm Query**

When the refrigerator's door is left open for a pre-determined alarm amount of time, currently put at 60 seconds, the device sends a Door Opening Alarm labelled message in the form of a SEND query. As the Agent receives a this message it sets the timestamp and state variables of its internal Last Alarm table, corresponding to this type of alarm, to the UNIX timestamp value received from the device and to *on*, respectively. If the Agent knows the EGGY's family registration data, as it should from the EGGY Login process, it calls the Web App to send an e-mail to its members in order to notify the current alarm situation, and to store this information at the Database.

**Temperature Report Query**

A Temperature Report is sent when the device detects a change in temperature over 1°C in one of the four samples per hour. As with the Door Opening Report, as the Agent gets this message it starts to force the turning off of the alarm to which it is associated if the new value for the current temperature is off the alarm domain. Following this the Agent checks if the device's status is Active and if that is the case it pushes the new data to the Web App, which should finally contact the Database in order to store it.

**Temperature Alarm Query**

When the device detects a temperature above a pre-established alarm limit, currently set at 11°C, it sends a Temperature Alarm labelled message in the form of a SEND query. As with the Door Opening Alarm, as the Agent gets this messages is starts by setting the adequate variables of the Last Alarm table and with that storing the alarm state, set as *on*, and its timestamp, shared by the device. Following this the Agent would reach the Web App which would later send an e-mail to the EGGY's family members acknowledging the alarm situation, as well as contact the Database to securely store this data.

### HTTP Channel

HTTP queries come from entities of the Web Platform other than the device, and are use to ask the Agent to perform tasks related to the management of its given EGGY, to store data that is to be shared with the EGGY upon one of its EGGTTP ASK calls, or to set or retrieve data regarding the Agent's operation.

#### Login Query

As depicted before (please refer to the beginning of this section for further detail on the Login process), the Login process is triggered by the Web App right after a BlinkUp over an EGGY is completed successfully and an Agent as been associated to it. The Login process cleanses the Agent's internal variables and fills a set of new ones with their default values, as well as creates a password which is then hashed and shared back with the Web App so that the latter could then perform the authentication of the given EGGY at the Web Platform.

#### Restart Query

The Restart call is used whenever a Re-BlinkUp is required by the user – This means that the user's EGGY has already been registered and operating normally but the user now needs the device to associate itself to a new WiFi network, which would happen if the user would change its domestic Internet Service Provider, for example. To accomplish the reconfiguration, the user would have to call the User App to perform a new BlinkUp over its EGGY and with that share the new network's credentials with the device, and upon the success of this procedure, the User App would call the Web App to complete the reconfiguration process, which would finally call the Agent to Restart.

As the Agent gets a Restart call it starts by cleansing its internal variables, similarly to the Login process. The Restart query would be filled with data, which was previously stored at the Database, regarding the EGGY Status, Nest and configuration variables from before the reconfiguration process was triggered, which the Agent stores locally. After this the Agent creates a new password for the EGGY authentication before computing its hash and sharing it back to the Web App in order to complete authentication process.

**Store Family Data Query**

After successfully authenticating the EGGY at a Login process, the Web App then sends a message to the given EGGY's Agent with data regarding its Family – The users associated to it. This allows the Agent to reach the Family in case of need, as in the case of reported alarms.

**Set Silent Mode Query**

The Set Silent Mode allows the User App to set the EGGY to stop or to start with its normal melody playing. The Agent stores the configuration sent locally, and forwards this information with the device the next time it connects and sends a query of the type ASK. This configuration is set as Boolean.

**Change Status Query**

The Change Status call allow the Web App to set any status for the given EGGY. The Agent stores this value locally and starts to act according to it.

**Reset Query**

The Reset call is self-explanatory since it simply relies on the reset of the Agent's internal variables to the default values. To ensure that this is only accessible to administrative usage, authentication is needed in order for the Agent to accept this call.

This list of procedures triggered by messages coming from remote entities of the Web Platform, namely the Web App and specially the EGGY device, would define the Agent's operation and its main purpose – To manage the operation of the device and to bridge it with the other entities of the Web Platform, in particular the platform's backbone known as Web App.

#### 3.2.1.2 Web App

The Web App is the backbone of the Web Platform, responsible to manage the connection of the Agent and the User App to the Database, to do all the heavy processing related to the management of the data and to supply the UI-related resources required by the User App.

### Technology and Tools

The development of the Web App relied on the use of a Linux based server to run PHP scripts built over a framework known as Fat Free Framework, according to an MVC architecture. The use of PHP is justified by the support available online from several years leading the web server code implementations worldwide, and by its versatility and simplicity. The Fat Free Framework would guarantee a sleek implementation of the PHP code and provide an API to easily reach the database format chosen – MongoDB (please refer to the section 3.2.1.3 for more detail on the Database).

### Architecture

The MVC (Model–View–Controller) architecture would bring a consistent structure to the web application by splitting responsibilities across these three main components – Types of objects – of the given architecture – A Model object would be responsible to manage data, logic and the rules of specific entities within the application, a View would be responsible to generate the representation of the data processed by a Model and a Controller object would become an entity responsible to listen to third party inputs, in this case coming from the User App, and translate them into commands to a Model or View object.

Figure 48 illustrates this architecture.

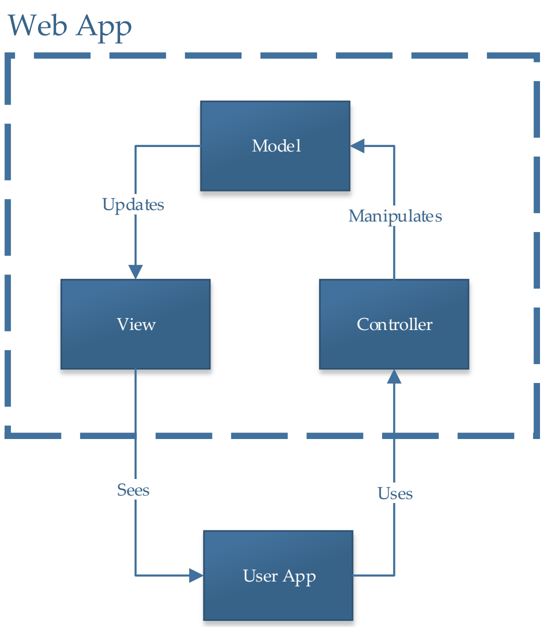



**Figure 48** **Illustration of the generic MVC architecture.**

Objects are instances that share a same backbone – Functions and properties. For example, a specific EGGY, identified by a specific unique ID and another set of common characteristics, but specifically filled, that define an EGGY could be defined as an EGGY object – As this is a specific instance of a common blueprint known as the EGGY type. The main blocks of the MVC architecture (Controller, Model and View) would also generate objects that would aggregate specific backbones while respecting each of their blocks' purpose.

More than a simple collection of routes to link HTTP requests to processes of Model objects, a Controller would have to combine services offered by these Model objects in order to reach the upper-layer results that would be under requirement, meaning that some logic would still have to be performed by a Controller. Model objects could then be seen as the performers of the basic operations, associated to very specific elements within the Web App, while a Controller would be an entity responsible to combine the results of those basic operations into more intricate answers to foreign requests. The design of this Web App would then inevitably have to start by defining the Model objects, their basic purpose and the basic services that they should be offering.

Eight main Model objects were implemented – The EGGY, Family, Reading, Data Frame, Login, Ranking, Alarm and Token. Each of these objects would aggregate a number of properties and functions associated to a same entity or purpose. The following describes three of these main Model objects.

### EGGY Model Object

An EGGY Model object would represent a device's instance. The main properties that would define an instance of an EGGY Model are listed in Table 13.

**Table 13** **The Web App EGGY Model main properties**

| Property Name | Property Type | Description |
|---|---|---|
| **_id** | Mongo ID | Associates the object to a Database's EGGY entry |
| **_status** | String | The Status of the specific EGGY device |
| **agentURL** | String | Holds the Agent URL of the object's EGGY device |
| **deviceId** | String | Associates the object to an EGGY device |
| **familyId** | Mongo ID | Path to a device's Family at the Database |

An EGGY Model object could be used to retrieve a device's instance through a given Mongo ID – That would relate it to a single entry of the Database – or through its very own device ID – Linked to the hardware, to reach its own device's Agent for performing tasks related to changing the device's settings or even its full reset, and to retrieve information about the device's status of operation. Table 14 lists the EGGY Model objects' main functions and procedures, their interface, reached entities and purpose.

**Table 14** **The Web App EGGY Model main functions and procedures.**

| Function Name | Main Input | Reached Entities | Main Output / Purpose |
|---|---|---|---|
| **FindsEGGYByID** | ID | Database | EGGY Instance |
| **FindsEGGYByDeviceID** | Device ID | Database | EGGY Instance |
| **SendFamilyData** | Family Instance | Agent | Sends Family data to Agent |
| **SendResetData** | EGGY Instance | Agent | Calls Agent of the given EGGY Instance to reset itself |
| **ChangeStatus** | Status | Agent | Sets a new status of the device |
| **SetSilent** | Sound Status | Agent | Sets the sound status of the device |
| **GetStatus** | EGGY Instance | - | Status |
| **GetAgentURL** | EGGY Instance | - | AgentURL |

### Family Model Object

The Family entity was conceived as a way to aggregate users around a device, as a device was targeted to a household and not necessarily to a single user – Families could be composed by one or more users. Every device would then be associated to a Family, as it would all the consequent behavioural monitoring and gaming experience. From the Web Platform's point of view, the Family would then be seen as the user, and a user would be considered as a property of a Family. The user as a property would have impact in the View, as characteristics as the user's age might determine the kind of dashboard the user would have access to. But the core data which would be used to mount that View would be the same among users of a same Family.

Table 15 lists the main properties of a Family Model object.

**Table 15** **The Web App Family Model main properties**

| Property Name | Property Type | Description |
|---|---|---|
| **_id** | Mongo ID | Associates the object to a Database's Family entry |
| **name** | String | The Family's name |
| **members** | Array | Array of users (type User) |
| **eggys** | Array | Array of EGGYs (type Mongo ID) |
| **points** | Integer | Current number of points associated to the Family |
| **eggoins** | Integer | Current number of EGGoins associated to the Family |

The Family Model object functions and procedures are mostly related with the processing and extraction of the properties of the Family that the given object represents but also the global querying of the Database for a specific Family object. Table 16 lists the main functions and procedures of a Family Model object.

**Table 16** **The Web App Family Model main functions and procedures.**

| Function Name | Main Input | Reached Entities | Main Output / Purpose |
|---|---|---|---|
| **GetMembersArray** | Family Instance | - | Members Array |
| **GetMember** | Index | - | User Instance |
| **GetSize** | Family Instance | - | Family Size |
| **FreezeFamily** | Family Instance | Database | Sets the Family's points' number to stop increasing |
| **UnfreezeFamily** | Family Instance | Database | Sets the Family's points' number to start to increasing |
| **FindBySearchQuery** | Query | Database | Family Instance |

### Data Frame Model Object

Data Frame is a structure created to hold compiled information about crucial metrics associated to an EGGY and its Family that would need to be accessed frequently. These Data Frames would be saved at the Database as a way to avoid recurring calculations that would have a considerable impact on the Web App's response time whenever one of these metrics would be required. Every Data Frame would be identifiable through a time interval and starting point, a source (as an EGGY or a Family), its data type and a unique Mongo ID which would associate it to a Database entry. Table 17 lists a Data Frame's properties.

**Table 17** **The Web App Data Frame Model properties**

| Property Name | Property Type | Description |
|---|---|---|
| **_id** | Mongo ID | Associates the object to a Database's Data Frame entry |
| **sourceId** | Mongo ID | ID of the source |
| **sourceType** | String | The source type (e.g. EGGY or Family) |
| **timeInterval** | String | Time interval considered in the compilation of data |
| **startTimestamp** | Mongo Date | Timestamp to the starting time of the compilation |
| **dataType** | Data Frame Type | The compiled information type |
| **value** | Mixed | The compiled information value |

This Model's functions and procedures would be related to the creation and finding of compiled data, and would heavily depend on accessing the Database as this would hold all the still relevant Data Frame records. Table 18 lists the main functions and procedures associated to the Data Frame Model.

**Table 18** **The Web App Data Frame Model main functions and procedures.**

| Function Name | Main Input | Reached Entities | Main Output / Purpose |
|---|---|---|---|
| **CreateData** | Data Frame Properties | Database | Creates compiled information from the inputted properties |
| **CreateOrUpdateData** | Data Frame Properties | Database | Creates or updates existing compiled information from the inputted properties |
| **FindsLastObjectData** | Source Type / Data Type | Database | Retrieves last object with given source or data type |
| **FindDataStats** | Source Type / Data Type | Database | Gets Data Frame results as statistics (Max, Avg...), using MongoDB aggregation pipeline |

In summary, these Model objects would be instantiated pieces of software that would aggregate functions and properties of basic elements of the Web App. As depicted before, these Model objects would be used by Controller objects to compute results and reply the more intricate queries coming from the User App. The following describes three of the main Controller objects – The API, the Statistics and the Points Controller objects. Besides these, the Application, the Communities, the Eggoins, the Third Party, the Users, the Settings, the Utils and the Admin Controller objects would complete this block.

### API Controller Object

The API Controller would be responsible for addressing basic operations as an EGGY login, retrieving EGGY information or posting EGGY readings. It uses the EGGY, Family, Alarm and Reading Models to achieve these goals. Table 19 lists the main functions and procedures associated to this Controller object.

**Table 19** **The Web App API Controller main functions and procedures.**

| Function Name | Main Input | Reached Entities | Main Output / Purpose |
|---|---|---|---|
| **login** | Authentication Data | EGGY Model | Logs in (authenticates) the EGGY into the Web App |
| **getEggyInfo** | EGGY ID | EGGY Model | Retrieves information about the EGGY in the JSON format |
| **putEggyInfo** | EGGY ID | EGGY Model | Puts information about the EGGY, e.g. regarding its status |
| **postEggyReadings** | JSON Data | Reading Model | Posts a reading and associates it to a particular EGGY |
| **getFamilyInfo** | Family | Family Model | Retrieves information about an EGGY's Family |

### Statistics Controller Object

The Statistics Controller has the purpose of computing statistics referent to a given EGGY's monitoring data. This objective would be commanded by a main function which would take use of the Controller object's remaining functions to complete its purpose. Three time intervals for these statistics were to be considered, namely Hourly, Daily and Overall. The statistics could then be door opening related or temperature related. The statistics main function would coordinate which sub-function to call according to timespan and type of the required statistics. This Controller would take use of the Data Frame and Reading Models.

Table 20 lists the main functions and procedures associated to a Statistics Controller object.

**Table 20** **The Web App Statistics Controller main functions and procedures.**

| Function Name | Main Input | Reached Entities | Main Output / Purpose |
|---|---|---|---|
| **getStats** | Stats Type / Interval | Reading Model / Data Frame Model | Coordinates the retrieving of the required statistics |
| **getDoorHourlyDetails** | Readings | - | Retrieves all door related stats information e.g. total time opened, average time per opening |
| **findAverageTemp** | EGGY ID | Data Frame Model | Calculates the daily temperature average. Return average temperature and final temperature of the given day |
| **findAverageTemp-Between** | Time Interval | Reading Model | Calculates the temperature average for a specific interval, typically one hour |

### Points Controller Object

The Points Controller would assume the processing of the game related variables, such as points, levels and EGGnergy boost levels (please refer to the section 3.2.2.2 for more information about the game design). It would rely on the EGGY, Family and Reading Models to achieve this goal. Table 21 lists the main functions and procedures associated to a Points Controller object.

**Table 21** **The Web App Points Controller main functions and procedures.**

| Function Name | Main Input | Reached Entities | Main Output / Purpose |
|---|---|---|---|
| **updatePointsFrom-Reading** | Reading Instance | - | Updates family boost and points after a door-opening event |
| **calculateCurrentPoints** | Family Instance | Family Model | Gets a Family's current points |
| **getBoost** | Time Boosting | - | Calculates the current EGGnergy boost level |
| **calculateLostBoost** | Door Opened Duration | - | Calculates the loss in the EGGnergy boost level from a door opening duration |
| **getEggvolutionTime** | Current Boost Lvl. | EGGY Model | Determines time to the next EGGnergy boost level |

#### 3.2.1.3 Database

The Database would be where the non-volatile data and the data that needs to be pre-processed before its usage in order to speed up the handling process would be stored.

**Technology and Tools**

The development of the Database relied on the use of an open-source non-relational database format called MongoDB which would bring a document based storage that could be easily accessed through the use of JSON-style objects, a popular format among web-based applications. The non-relational characteristic would allow the development of a dynamic database devoid of an inflexible backbone which would grant it scalability and margin to evolve and to avoid prospective future constraints.

The MongoDB defines two main data structures – Documents and Collections. Documents are the database's records and are composed of field and value pairs, according to the JSON syntax. But MongoDB stores this information on disk in a serialized JSON format called BSON, which also extends the data types allowed by the JSON format. The values of fields may contain other Documents, arrays, and arrays of Documents. Documents are identified by a unique _id field, which acts as a primary key. Collections, as the name implies, are collections of Documents, and, as so, are analogous to tables in relational databases. However, unlike a table, a Collection does not require its Documents to have the same layout.

As an analogy, Documents could be seen as cards that would be put inside very permissive bags called Collections. The Collection bags would just define that the cards in it would closely represent a same object, in a very fuzzy way. But picking up two cards randomly of a same bag wouldn't guarantee them to have exactly the same structured information. The tie between two cards of different bags (as in the relationship between an EGGY and its Family) would be achieved by each card storing each other's unique ID. By picking up any EGGY card we could then immediately find the corresponding Family in the Family Collection bag.

**Architecture**

The database's current implementation is defined by seven Collections – Families, EGGYs, Readings, Alarms, DataFrames, Rankings and Tokens. Four of these are dissected in the following paragraphs.

### Families Collection

As depicted in the previous section of this Chapter, the Family is a structure that was designed with the purpose of aggregating several users around a same EGGY, as an EGGY would be part of a household and not a property of a sole user. A document belonging to the a Families Collection would always have the same initial structure and its data interpretation would always be the analogous, independent of any given field – A Family document would always represent a Family entity – a collection of users and its own properties.

Table 22 lists the typical fields of a Family Document, Table 23 lists the fields of a User element.

**Table 22** **The Database's typical Family document.**

| Field Name | Format | Filled Upon Creation | Filling Options / Description |
|---|---|---|---|
| **_id** | Mongo ID | Yes | The unique ID of a single Document |
| **createdAt** | Date | Yes | The creation date of the given Document |
| **eggoins** | Integer 64-bit Signed | No | The current amount of EGGoins banked by the Family |
| **members** | Array | Yes | An Array of the members of the Family – The App users |
| **name** | String | Yes | Family Name |
| **eggys** | Array | Yes | Array of the EGGYs associated to the given Family |
| **points** | Double | No | The Family's current number of points |
| **pointsRegBoost** | Integer 64-bit Signed | No | The main EGGYs current door-opening related EGGnergy boost level |
| **pointsTempBoost** | Integer 64-bit Signed | No | The main EGGYs current temperature related EGGnergy boost level |
| **pointsUpdate** | Date | No | The date of the last update to the points |
| **size** | Integer 64-bit Signed | No | The Family's size (member number) |
| **pictureId** | Mongo ID | No | ID to the Family's picture |
| **position** | Integer 64-bit Signed | No | The Family's current position at the overall Ranking |

**Table 23** **The Database's User structure.**

| Field Name | Format | Filled Upon Creation | Filling Options / Description |
|---|---|---|---|
| **email** | String | Yes | User e-mail / unique ID |
| **gender** | String | No | User gender |
| **name** | String | Yes | User name |
| **password** | String | Yes | Hash of the user's password |
| **confirmedEmail** | Bool | Yes | *True* if e-mail has been validated |
| **birthday** | Date | No | The user's birthday |

### EGGYs Collection

The elements of the EGGYs Array present at a Family Document would point to a Document of an EGGYs Collection. This would hold the information related to a specific EGGY. Table 24 lists the typical fields of an EGGY Document.

**Table 24** **The Database's typical EGGY document.**

| Field Name | Format | Filled Upon Creation | Filling Options / Description |
|---|---|---|---|
| **_id** | MongoID | Yes | The unique ID of a single Document |
| **agentUrl** | String | Yes | The EGGY's unique Agent URL |
| **_status** | String | Yes | The EGGY's status (Newborn, Active, Inactive, Vacations) |
| **deviceId** | String | Yes | The unique EGGY ID, associated to the hardware |
| **hash** | String | Yes | The EGGY's password, hashed, used for its authentication |
| **settingUnit** | Integer 64-bit Signed | Yes | The temperature unit used by the given EGGY |
| **settingSilent** | Integer 64-bit Signed | Yes | The sound setting of the device |
| **firstActivity** | Date | No | The date to the first activity (report) registered |
| **lastActivity** | Date | No | The date to the last activity (report) registered |
| **familyId** | Mongo ID | Yes | The ID of the EGGY's Family |
| **name** | String | No | The EGGY's name |
| **nest** | String | No | The EGGY's Nest e.g. None, Fridge |

The Family ID present at an EGGY Document would create a bidirectional relationship between a Family and an EGGY.

### Readings Collection

Each Document of the Readings Collection would represent a piece of data reported by the EGGY. The Documents of this Collection would then have a greater variability among themselves than would those of the previously depicted Collections, as different types of reports would be aggregate in this Collection. The generic structure is shown in Table 25.

**Table 25** **The Database's Reading document.**

| Field Name | Format | Filled Upon Creation | Filling Options / Description |
|---|---|---|---|
| **_id** | Mongo ID | Yes | The unique ID of a single Document |
| **timestamp** | Date | Yes | Timestamp of the report |
| **eggyId** | Mongo ID | Yes | Link to the EGGY which issued this report |
| **label** | String | Yes | Label to the kind of data reported e.g. TempEvent, DoorEvent, … |
| **data** | (Mixed) | Yes | The data reported |

Although the Reading Documents' filling would have a greater variability its structure would be the most rigid of the depicted Collections so far, as every Document would be expected to hold these five basic fields since its creation.

### Data Frames Collection

As the Reading Documents, the Data Frame ones also have a very strict (self imposed) structure but a very high variability among each one. As presented before, Data Frames are pieces of compiled information, made from calculations upon several Readings, that need to be accessed frequently. For example, a Data Frame could represent a number of a refrigerator's door openings during a certain interval. To avoid constant calculations, these Data Frames are stored in the Database while they are still relevant – They are deleted after it.

Table 26 depicts the structure of a Data Frame Document. Table 27 shows some examples of Data Frames' filling.

**Table 26** **The Database's Data Frame document.**

| Field Name | Format | Filled Upon Creation | Filling Options / Example |
|---|---|---|---|
| **_id** | Mongo ID | Yes | The unique ID of a single Document |
| **lastUpdate** | Date | Yes | The last update on the Data Frame |
| **startTimestamp** | Date | Yes | Timestamp of the beginning of the time interval considered for the given Data Frame |
| **timeInterval** | String | Yes | The time interval of the given Data Frame |
| **sourceType** | String | Yes | The source type of the given Data Frame (e.g. EGGY or Family) |
| **sourceId** | Mongo ID | Yes | The ID to the source |
| **dataType** | String | Yes | The data type |
| **value** | (Mixed) | Yes | The data |

**Table 27** **Examples of Data Frames' filling.**

| Data Type | Source Type | Time Interval | Value Format / Description |
|---|---|---|---|
| **TEMPERATURE** | EGGY | Hour/ Day / Week | Double / Accumulated temperature |
| **DOOR** | EGGY | Day | Object / Holds several metrics related to the daily door openings – Count, Avg Time, Min Time, Max Time, Morning / Afternoon / Evening Openings, … |
| **POINTS** | Family | Day | Number of points achieved in a particular day |
| **GLOB_RANK** | Family | Day | The Global ranking of a Family at the end of a day |

#### 3.2.1.4 User App

The User App is the entity responsible to bridge the user with the Web Platform by transforming the data and the interaction with it into a visual interface. This app would be called the EGGY Yolk.

**Technology and Tools**

The development of the User App relied on the use of Javascript (plain, with a contribution of JQuery), CSS and HTML web-development programming languages, and also on Java and Objective-C for the development of Android and iOS hybrid applications, respectively.

**Layout**

The User App was designed to have all its main operation to be runnable, and the entire layout to be held, in a web environment and leaving only specific, peripheral tasks to the native mobile environments when necessary. The entire main interface would then be available on any browser, accessible through any mobile or desktop device, which would develop considerably the number of prospective users, over the development of native application for any specific platform. In mobile devices this interface would be achieved through the use of a Web View, a window to a web environment built over a native application. Figure 49 illustrates this.

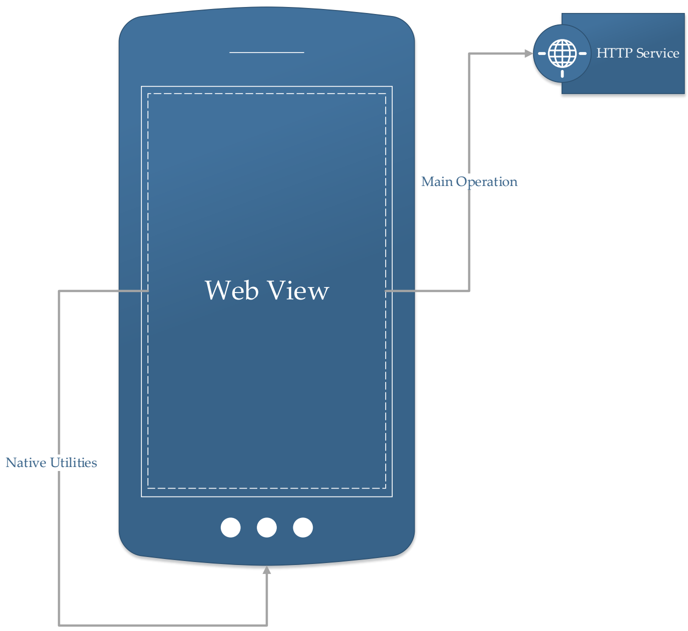



**Figure 49** Representation of the Web View developed and its two main channels.

All the pages of this user interface were designed to respect the same generic backbone that could be described by three main elements – Header, Body and Footer. The Body would also be divided between three sub-elements – The Body Header, the Body Content and the Body Footer. This would define a card-like layout, as depicted in Figure 50.

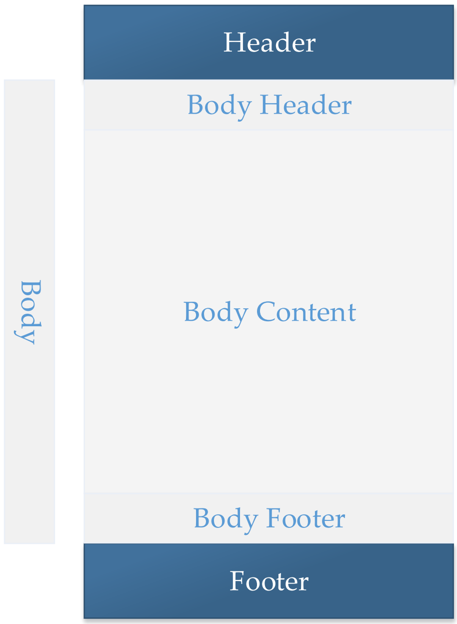
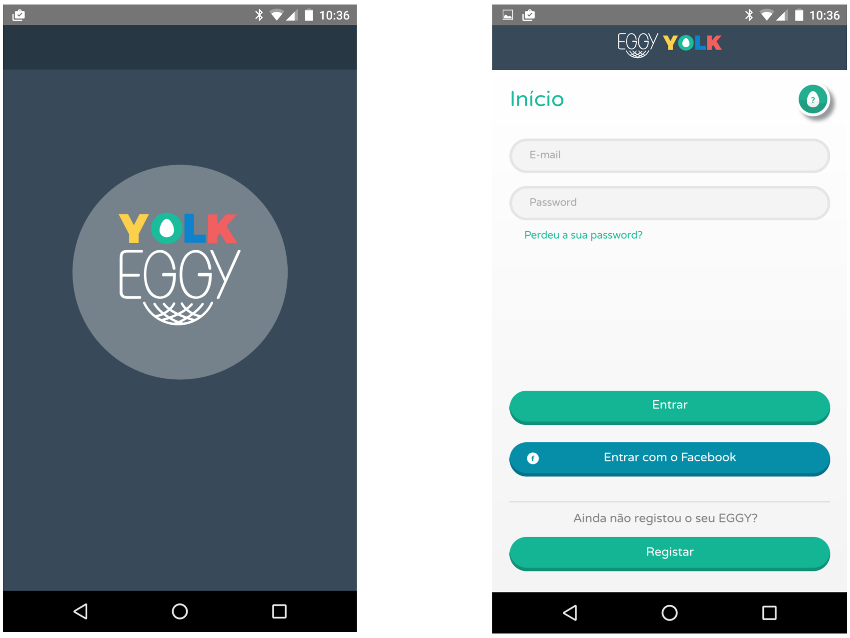



**Figure 50** Illustration of the UI's generic layout.

**Login & Registration**

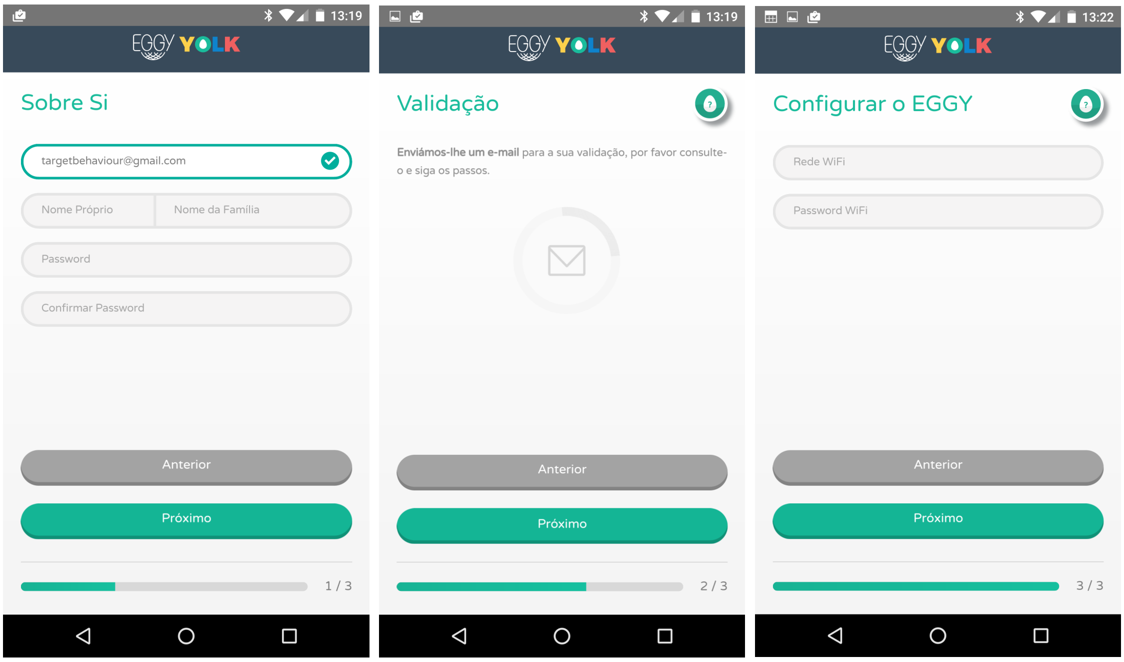
The user's first contact with the User App would lead it to a page for login or registration of an account. The login would be available to be authenticated through an e-mail and password, or through a Facebook account. Clicking on "Entrar com o Facebook" would make the User App to reach the Web App in order to check if the user with the cached Facebook account was already registered. If that would be the case, the Web App would redirect the User App's view to the user's Dashboard. If not, the User App would have its view to be redirected to the user's registration with that given Facebook account. Clicking on "Registar" would start an e-mail based registration of a new user account, while clicking on "Entrar" would validate the inputted credentials. Figure 51 illustrates this on-boarding.

The registration would follow three main steps. The first would have the purpose of getting basic information about the user and its authentication – namely its name, surname, an e-mail and password. The second step would serve to validate the inputted e-mail address – An e-mail holding a button for validation would be sent and clicking this button would trigger the User App to automatically change its view to the next and final step. This last step would complete the registration process by configuring and performing the BlinkUp of the device.




(1) (2)

**Figure 51** **User App's on-boarding.**




(1) (2) (3)

**Figure 52** **Illustration of the three steps of a user registration process.**

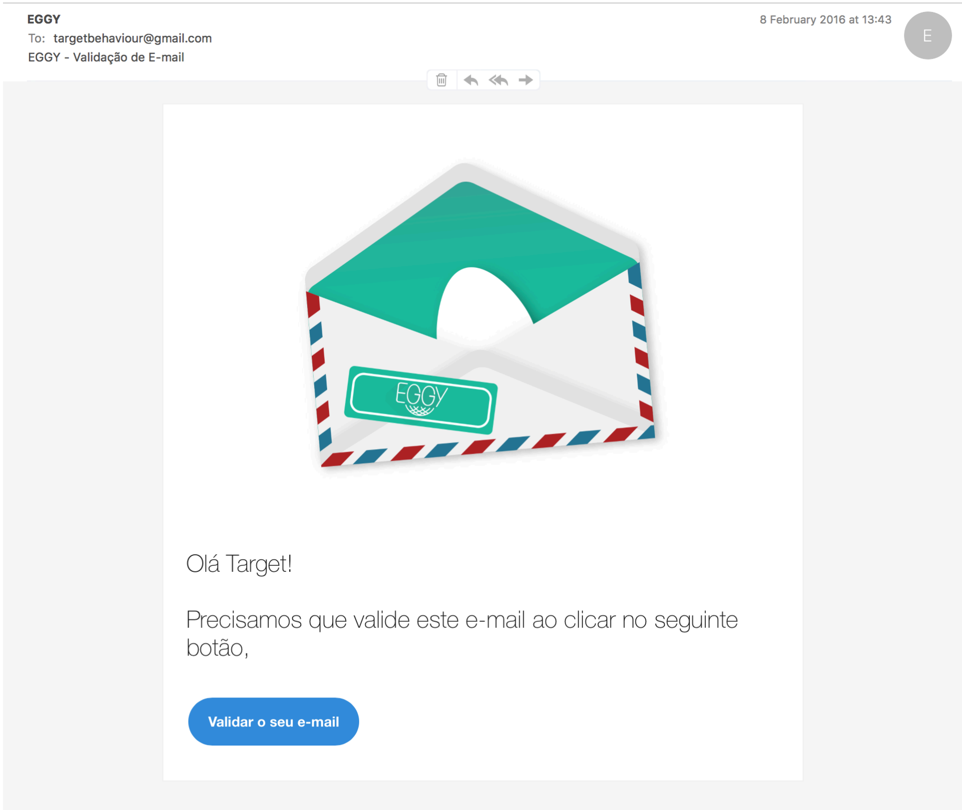



**Figure 53** **Illustration of the registration's confirmation e-mail.**

The first step would simply demand the insertion of personal information, upon which some basic verification of the e-mail structure (and its uniqueness in the Database) and password constraints (as size) would be made to allow moving into step two.

As stated, on step two it would be required to the user to validate the inputted e-mail, by clicking on a button part of the content of an e-mail that it would be sent to it, as shown in Figure 53. The User App would be periodically asking the Web App to validate if a field of the Database associated to the Family Document being registered (a field named *emailConfirmed* – Please refer to the Database section of this Chapter) would have been set to *true*, and if this would turn to be the case the View would immediately move into the final step. Clicking on the button to move forward would also trigger this behaviour.

Finally step three would just validate that inputs were given about the WiFi network's SSID and WEP, WPA or WPA 2 Personal password.

From the moment that a user would first start a registration process a Family entry would have been created at the Database, but this would be associated to a time to live. Only after all the inputs would have been validated and the BlinkUp process (which would configure the user's EGGY to connect to its home WiFi network) completed successfully would the registration be completed and the Database data stored permanently. So the most relevant, and problem prone, phase of the registration process would happen after the User App's BlinkUp performing, as it would demand the User App to reach the Web App to access the Database and the EGGY's Agent to complete the registration.


(1) (2) (3)

**Figure 54** **Illustration of the pre-BlinkUp pages of the registration process.**

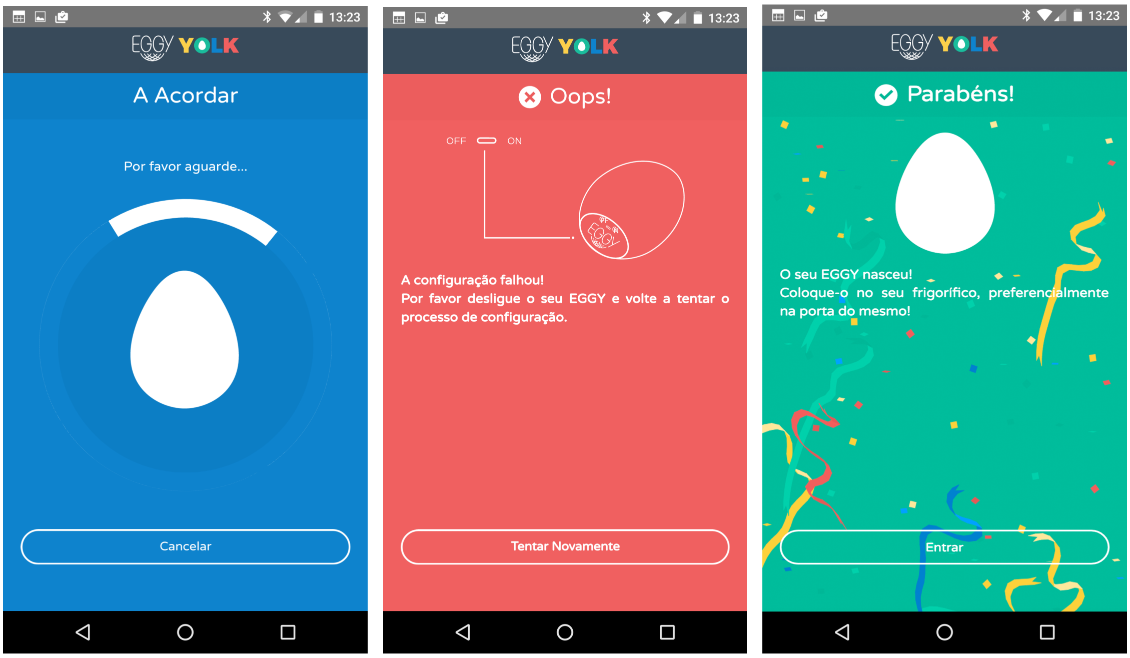
Before the BlinkUp the user would be guided to prepare it through three sequential panels. The first would show a disclaimer and the necessary care with performing the BlinkUp for epilepsy patients, as the screen of the user's mobile device would be put to flash intensively. The second would indicate the user to turn on the EGGY device. The last one would ask the user to lay the EGGY on top of the mobile device's screen and click a button to start the BlinkUp. Figure 54 illustrate these collection of panels.

At this point the web-based interface, provided by the Web View, would have to call native software in order for the User App to take hold of the hardware API and achieve the desired sequence of flashes according to the inputted WiFi credentials that would communicate these to the EGGY device. Two different methods to bind the web-based environment with the native environment were used for the Android and iOS implementations respectively.

As the Android is programmed in Java, a relative to the Javascript used in the programming the front-end of this web application depicted so far, a binding library would already be available on its basic SDK. On the Android side, after a configuration of the application's manifest and a few lines of code in the main runnable file to enable the Javascript interface, the functions part of this interface would just have to be annotated with "@JavascriptInterface" in order to make them accessible on the Javascript side. There, on the Javascript side, a call to one of these functions could be achieved as calling a method of an Android object, as *Android.function(parameter)*. As an example, the function to start the BlinkUp by the device would be called by an *Android.startBlink(ssid, pass)*.

The iOS implementation would require a custom interface. The device was put to sniff every request made by web-environment, mostly of the HTTP type. Mostly, and not totally, because as a way to tell the device that it was expected to temporarily take hold of the operations for performing a particular task a collection of requests of the type EGGTTP would be used. While sniffing requests, ever time that device would detect an URL scheme as "*eggttp://*" it would consider the message to be destined to itself. The URL path would then tell the device which function to run. As an example, the function to start the BlinkUp by the device would be called through a request as *window.location = 'eggttp://BlinkUp?ssid='+ssid+'&pass='+pass*.

After the hardware call, the BlinkUp process would be similar in both Android and iOS platforms. A countdown of three seconds would be set, after which the device's screen would be put to flash according to the credentials provided. After the flashing the device would use the interface with the web-environment to ask the Web App to set a View to acknowledge the user about the progress on the EGGY's configuration, depicted in (1) of Figure 55. At this stage the device's would be waiting for the EGGY, supposedly now connected, to signal that the BlinkUp was successful and that it was able to connect to the user's WiFi network. A one-minute slot would be given for the EGGY to complete this task. If no signal would be received within this time, the device would consider the BlinkUp to have failed and it would ask the Wep App to change the View to the panel (2) of Figure 55. The user could also trigger this behaviour by clicking on "Cancel" while waiting for an answer – If a signal from the user's EGGY would be received after that it would be ignored. If the EGGY would fail to connect this panel would prompt it to review the credentials and restart the process again.




(1) (2) (3)

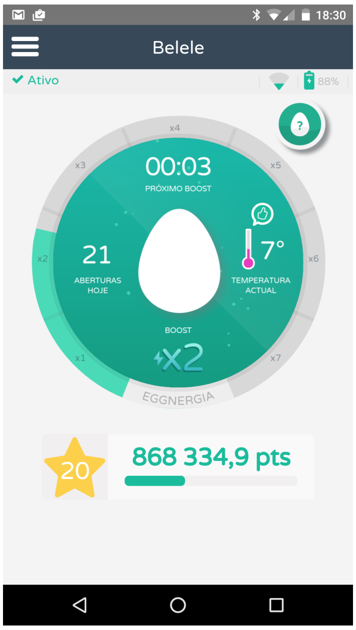
**Figure 55** **Illustration of the consequent panels of the BlinkUp process.**

If the EGGY would achieve a connection, it would have an Agent assigned to itself and its unique EGGY ID and Agent URL would be received as a signal by the user's, by he time sniffing, device. The device would then consider its task of performing a BlinkUp to be completed and would use the interface with the web-environment to finally call the Web App to complete the user's registration and the EGGY's login (More about this process is detail in the Agent section of this Chapter). If the EGGY's Agent together with the Web App would be able to complete the EGGY's login then the Family's registration would be saved permanently and the User App's View would change to the panel (3) of Figure 55. Clicking "*Entrar*" would finally lead the user to its Dashboard for a first time.

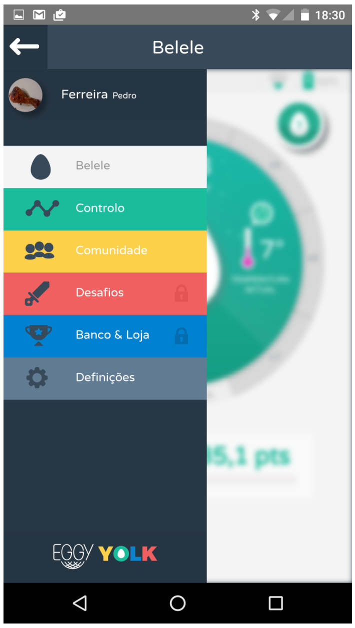
### Dashboard

The EGGY Yolk's Dashboard is composed by six sections, namely the Dial, the Control, the Community, the Challenges, the Bank&Store and the Settings sections.

The Dial section is the welcoming one – To which the user first gets upon logging in. This section is intended to give an overall look about the EGGY's status and core gaming variables. As the implementation of the game behind the EGGY's monitoring relied on the Energy Model (please refer to the Game Design section of this Chapter) the relevant gaming variables would be the current points, level and the EGGnergy boost level. Besides this, the total number o door openings of the due day, the current temperature measured, the time of door closed required to move into the next EGGnergy boost level and the points required to the next level (in the form of a progress bar) are present in this View.




(1)




(2)

The EGGnergy boost level progress was illustrated in the form of a circular dial, which would name the section. This would determine how fast would grow the points, illustrated below. The timer at the top tells the user for how long it should keep the refrigerator door closed in order for its EGGY's EGGnergy boost evolve to the next level – In the case illustrated above, the time to reach level x3.

The temperature dial would tell the user if the temperature is under the thresholds of the ideal and, consequently, if a bonus of a unit in the EGGnergy boost level would be active. The icon above this temperature dial would reinforce this, as a freezing icon is shown if the temperature is below the ideal, as it is a flaming one if the temperature happens to be above the ideal.

The current level is shown inside the yellow star and, as stated before, the progress bar to the right of it indicate the amount of points gathered while in the current level and the amount required to move into the next one. Above this bar the total amount of points gathered so far is shown.

The top-bar menu would always be present throughout the entire Dashboard and it would be the main navigation mechanism between the several Sections that compose it. Two of these Sections were still to be developed by the time of the publishing of this document – The Challenges and the Bank&Shop, and were to be excluded of the first pilot test.

### Control Section

The Control Section is the one destined for the user get to control its own behaviour – To check the monitoring data reported by its EGGY. This data is divided between three timespans – Daily, Weekly and Overall. The home View of this Section lists a set of sub-dashboards, called Cards, which can be accessed. There is a Card for every past weekday, a Card for the current week and a Card for the Overall.

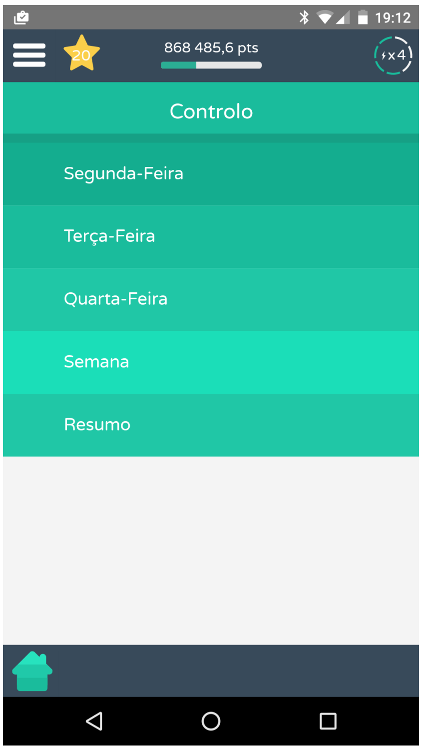
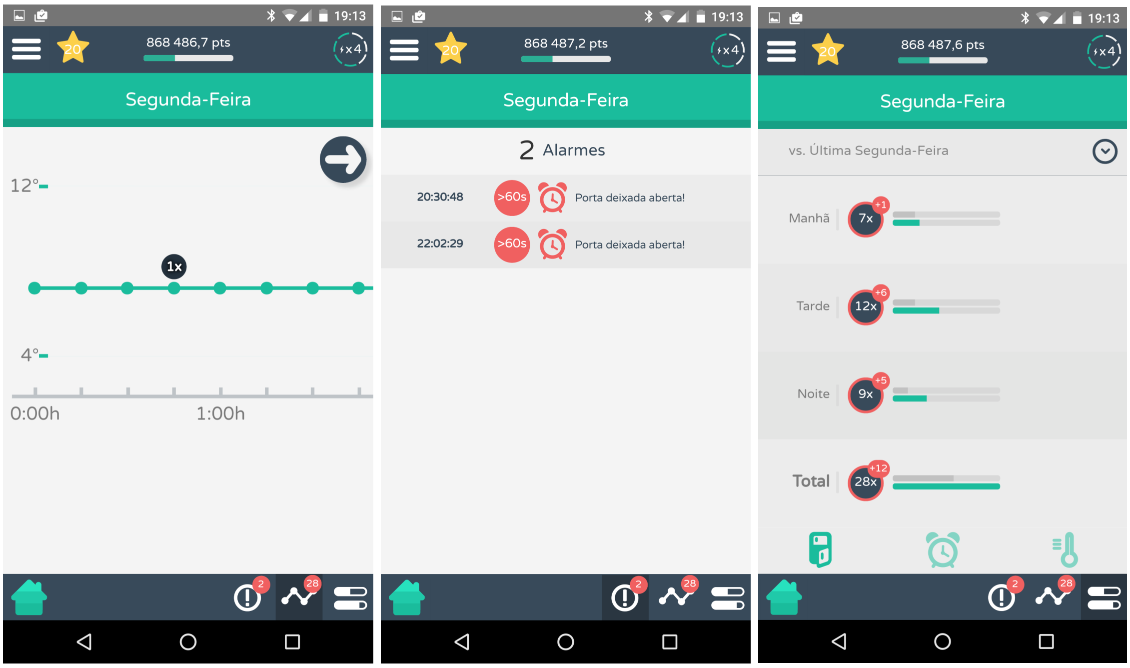



**Figure 56** **Illustration of the Control Section home View.**

A daily Card would have three main components, called Widgets – A Graph Widget, an Alarms Widget and a Comparison Widget.

The Graph Widget would allow the user to check the refrigerator's temperature variations and door openings in real time. A discrete graph of the temperature, with samples distanced 15 minutes each, would be constructed over day. The number of door openings between two of this samples would be illustrated with an icon on top of the initial point holding the number of door openings in that interval (e.g. in (1) it is acknowledged that one door opening happened between 00:45 AM and 01:00 AM). By clicking one of the graph's points, a popup View with the details of that sample, namely the accurate temperature reported and the list of door openings – Which would show the timestamp of every event and its duration – would be shown.




(1) (2) (3)

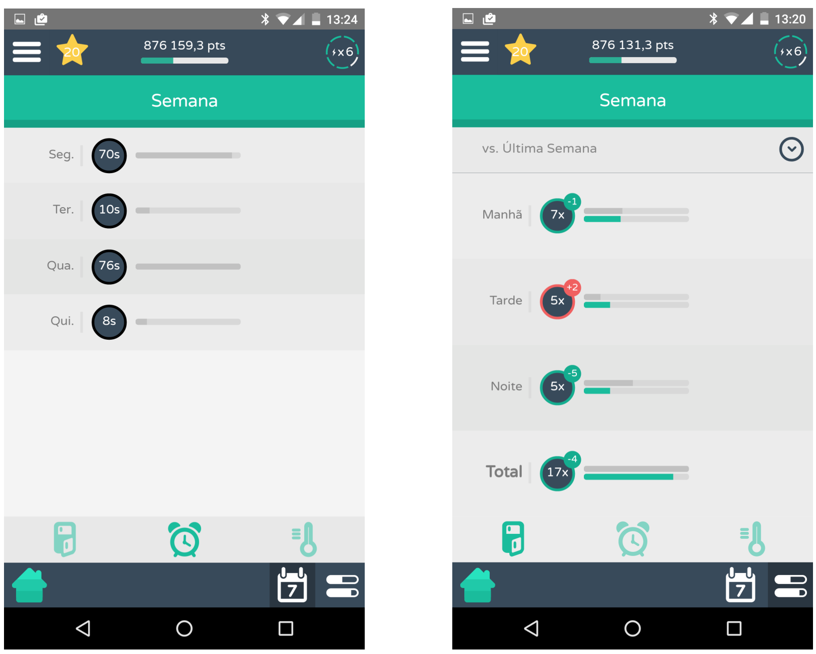
**Figure 57** **Illustration of the Control Section's daily Card's Widgets.**

The Alarm Widget would list the alarms reported by the user's EGGY. These alarms could be of the type Door Alarm or Temperature Alarm. A Door Alarm would be triggered if the refrigerator's door would be detected to be opened for more than 60 seconds. Besides adding the alarm to this dashboard, an e-mail would also be sent to the user to notify it about the situation. A temperature alarm would be triggered if the temperature would be detected to be over a maximum threshold, set at 11°C. As in the case of a Door Alarm, an e-mail would also be sent to the user to acknowledge the alarm.

The Comparison Widget would allow the user to compare a day's results with those from previous days – by default, the same weekday of the week before, but other comparisons would be permitted, as with the current day or the same weekday of past weeks. This comparison would be divided between three categories – Door openings, door openings' duration and temperature.

Every comparison would be illustrated by three elements. Two progress bars, a green representing the current value and a grey one representing the past value, would give a sense on how distant are the two values being compared. A circular dial would quickly tell the user if the current value is better or worst than the past one, by signalling this circle with a green or red rim, and also how better and worst it is – The value inside the inner circle would hold the current value, while the value inside the smaller circle in the corner would tell the (positive or negative) difference between the current and the past values.

A Card of a current week would be similar to that of a weekday with the difference that instead of daily metrics weekly metrics were to be considered. The Graph Widget would be substituted with a Weekly Overall Widget in which the achievements of every past weekday of the current week so far would be listed in a single View. The Comparison Widget would be very similar but it would be used to compare full weeks.




(1) (2)

**Figure 58** **Illustration of the Control Section's week Card's Widgets.**

Finally the Overall Card would hold a single Widget in which the overall results of the user's EGGY monitoring are shown, grouped by the three categories common to the previously depicted Cards. Figure 67 illustrates this Card.

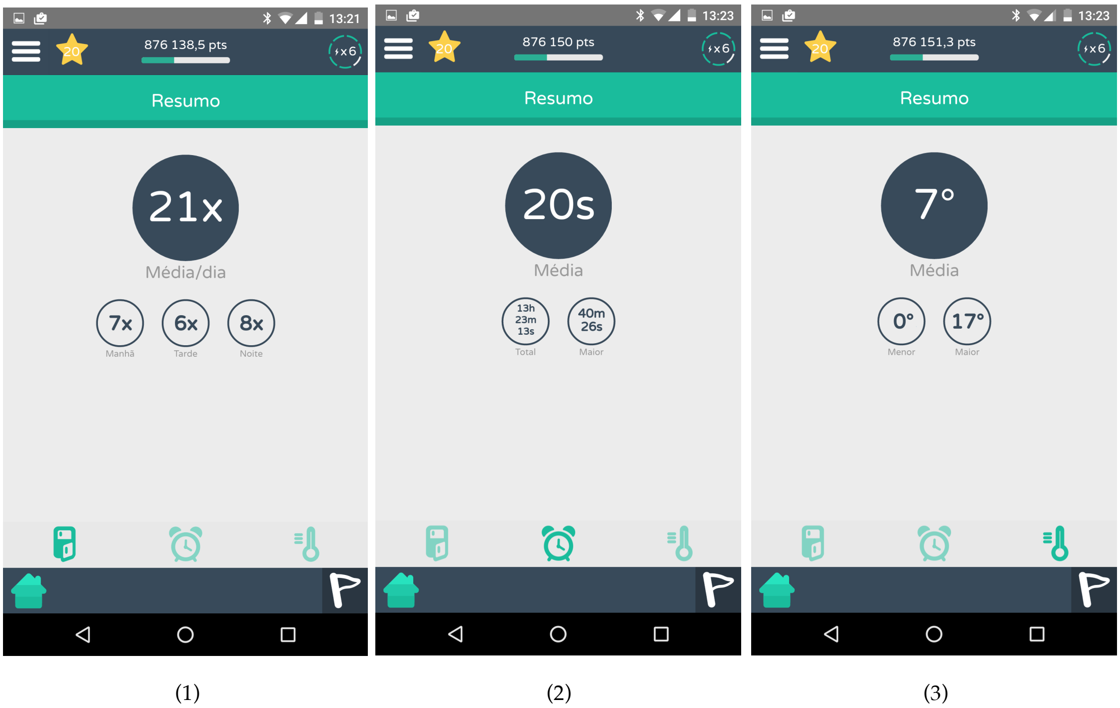


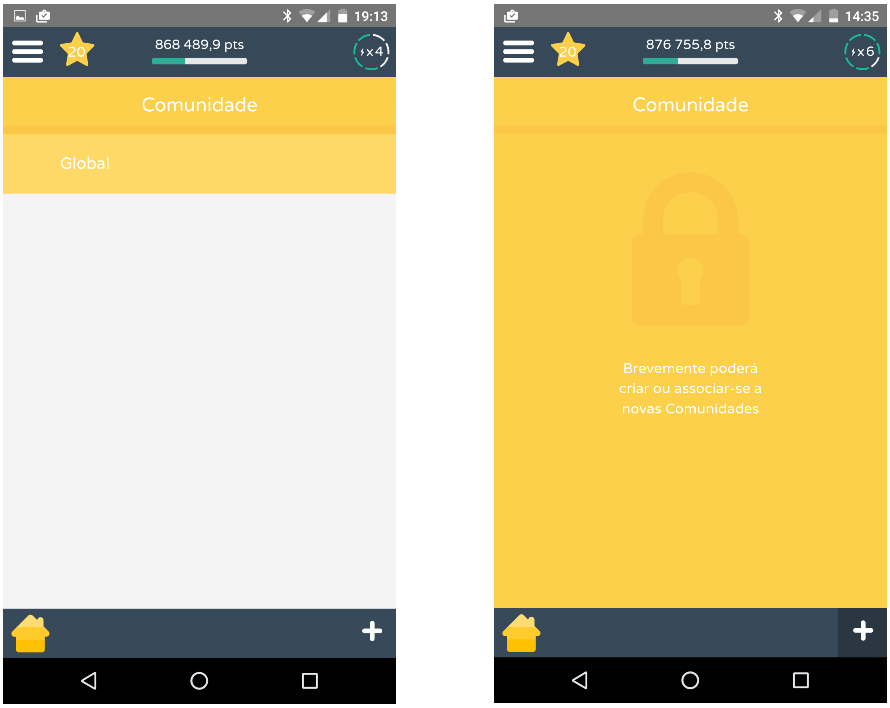

**Figure 59** Illustration of the Control Section's Overall Card's Widget.

### Community Section

The Community Section is where users are aggregated into Communities, where they are given tools to compare each other behaviours towards their refrigerator and where they can check their positions inside several types of rankings within every Community that they are part of.

This Section's home View would list the Communities that the user is part of and also allow it to join a new one. At the time of the publishing of this document, only the Global Community, composed by all the members of users of the EGGY Yolk, was available – The functionality to build new Communities was blocked. By clicking a Community the user would get access to its Card-like sub-dashboard.

Figure 68 illustrates the Community Section's home View.



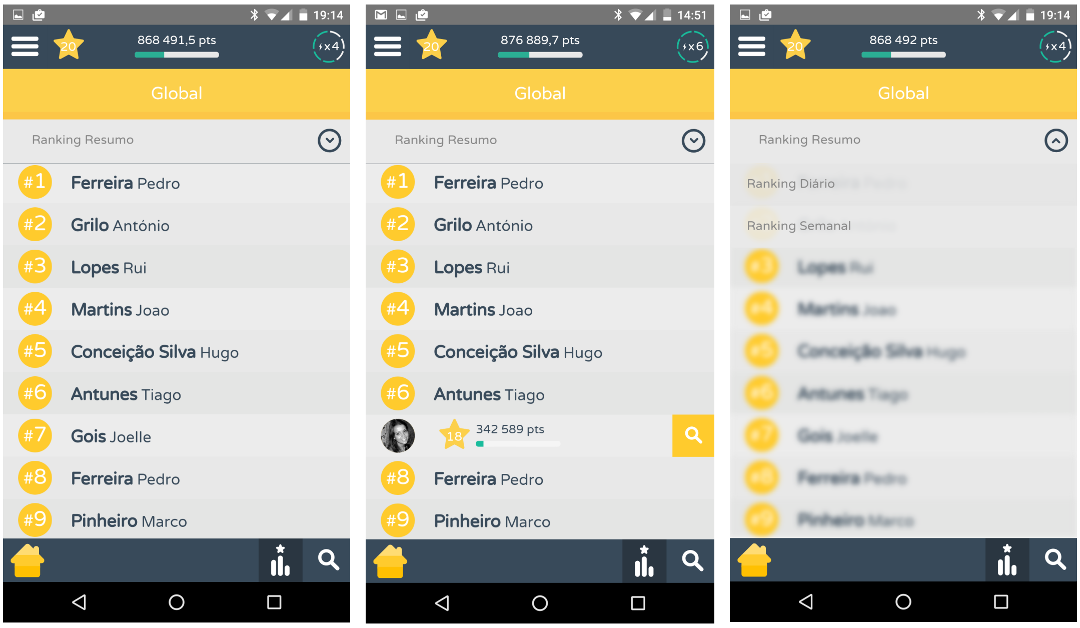

(1) (2)

**Figure 60** **Illustration of the Community Section home View.**

A Community Card would be composed by two Widgets – A Ranking Widget and a Search Widget.

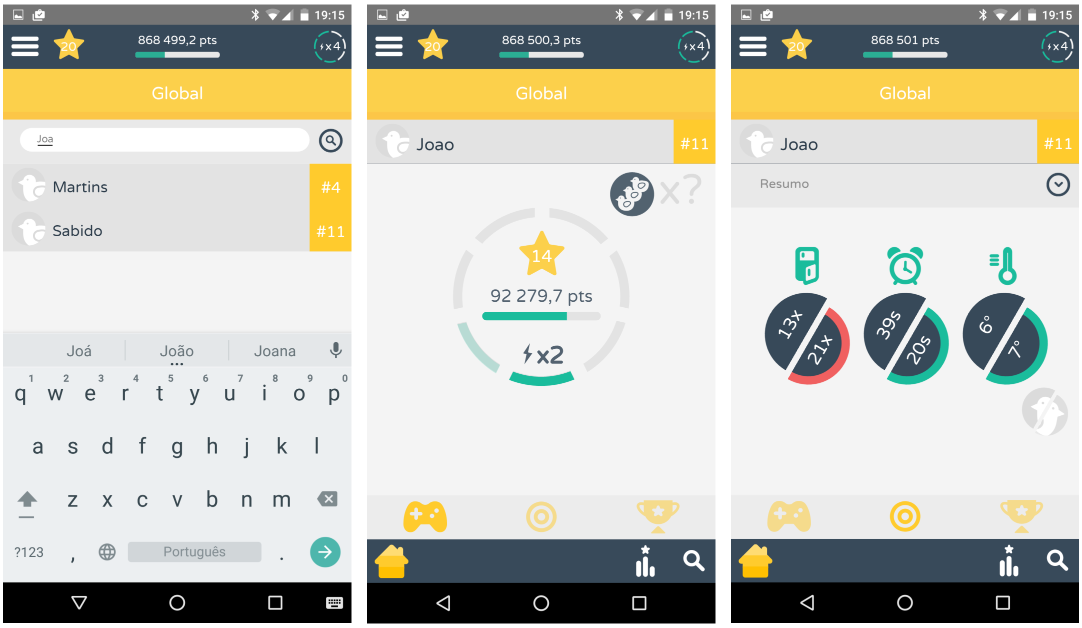
The Ranking Widget would list the users according to three rankings – Daily, Weekly and Overall. These rankings would be based on the number of points gathered during each of the time intervals (please refer to the Game Design section of this Chapter for more detail). By tapping one of the listed members of a ranking a set of information about that user would fill its slot – A user would see the number of points, the level, the points' progress bar to the next level, a picture of the user and a button to get to that user's User Card.

The User Card would hold extended information about a user – About the gaming variables, the behavioural patterns and achievements. A User Card could be reached by tapping a user in a ranking or by using a Community's Search Widget and typing part of the name of the user or a position in any of the Community's rankings (as "#5 in the weekly ranking"). A User Card would be divided between three categories – Gaming, Behaviour and Achievements. The first would show the user's gaming metrics, as points, level and EGGnergy boost level. The second would allow a user to compare its own behaviour with that of the User Card's subject, regarding the daily, weekly and overall behaviour. Lastly, the achievements category would allow the user to check the searched user's achievements and rewards, such as EGGoins and badges.




(1) (2) (3)

**Figure 61** Illustration of a Community's Card Ranking Widget.




(1) (2) (3)

**Figure 62** Illustration of a Community's Card Search Widget (1) and of the User Card found in a search (2-3).

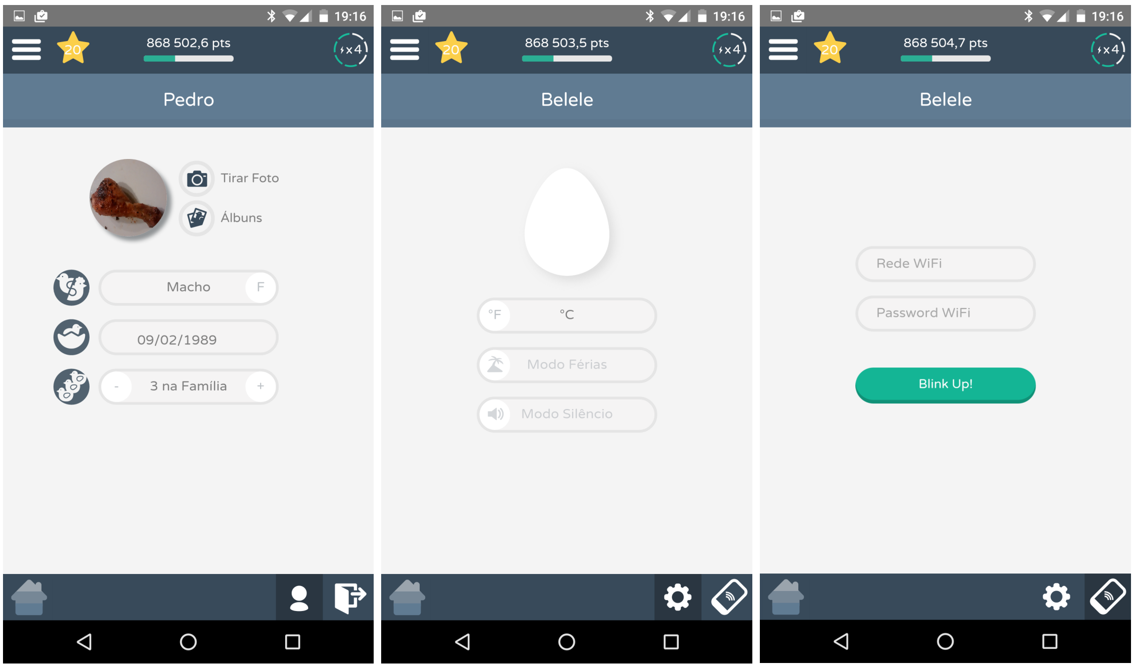
### Settings Section

The Settings' home View would declare the settings to be separated between two entities, which would lead to two Cards – The EGGY's and the User's.

The User Settings Card would allow a user to change its personal information, as the gender, birthday and family size, and also add a picture from its device's album or accessing the camera to get a new one. To achieve capturing a photo from the device, the User App would have to rely in the web-to-native interface, depicted before in this section, as it was used for the BlinkUp process. The User Settings would also be the place for the user to perform a logout.

The EGGY Settings Card would allow the user to configure the EGGY settings, namely enabling/disabling the beeping, enabling the Vacations status (please refer to the Game Design section of this Chapter for more information), and setting the temperature unit, but also performing a new BlinkUp.

Figure 63 illustrates the Settings' Cards.




(1) (2) (3)

**Figure 63** **Illustration of the Settings' User (1) and EGGY (2-3) Cards.**

Additionally, to the feedback through the web-based User App, accessed either through a desktop browser, iOS or Android mobile applications, it was understood that, especially at this early-stage of engagement of the app, it would be necessary to bring notifications to the user, about its behaviour and achievements, on a regular basis. This was for now implemented with e-mail notifications, sent everyday at 8AM, holding a wrap-up of the day before. It resumes the accumulated behaviour for that day and the ranking status at the end of that day.


**Figure 64 Illustration of the daily resume feedback e-mail.**

### 3.2.2 Game Design

As stated at the introduction of this work, a very important part of this human-centred approach to energy efficiency promoting technology would be the engagement on an emotional level. Signing an emotional contract with the user was known to bring a considerable development of the user's drive to its own behavioural improvement. To achieve this goal, this implementation would rely on, and later test, the gamification of the device's interface – The use of artefacts and rules commonly seen in games to engage the user. But gamification was not to be considered as a standardized solution ready to load into any given project, as it was understood that a misfit implementation could even lead to deteriorate the user's relationship with the gamified subject. So this gaming experience had to be carefully thought in order to make sense in the context it was about to be put in.

This chapter describes two gamification perspectives, which are called the Allowance Model and the Energy Model.

Both models were built over the idea that a metric to quantify the collection of good and bad behaviours by the user had to be developed, in order to allow merging the broad number of variables associated to behaviour towards energy efficiency at home and to make the comprehension of good and bad simpler to the user. Ultimately this metric was to be considered as a virtual currency in both models, called the *EGGoin*. The compiling of this metric into a currency is justified by both models' goal to reward the best performing users with intrinsic and extrinsic offers, which could then happen through redeeming this currency.

#### 3.2.2.1 The Allowance Model

The Allowance Model is set over a financial basis – The user would be given an amount of EGGoins to manage during a certain period of time, set at a week, and would have to spend part of this amount per every energy consumption impacting behaviour – Just as a typical allowance. An example of a behaviour which would be under a need to pay EGGoins for would be a door opening of a refrigerator for a certain amount of time. At the end of each week, on the 0 hour of every Monday, a balance of the past week would be checked and the remaining of the week's allowance would go into an EGGoin bank, which could then be used as currency for redeeming offers promoted by the platform. This EGGoin working capital would never go negative, would be flatted to zero whenever the bad behaviours would extend those allowed by the allowance, so the EGGoin bank would never be subtracted from it.

The amount of EGGoins to be set as the allowance would have to be dimensioned so that a week of complying behaviours would grant a positive remaining of EGGoins at the end of it. And of course with it would also have to come the dimensioning of the cost of EGGoins to pay per energy consumption impacting behaviour. The value of an EGGoin was to be defined.

Another challenge to complete the task of determining the value of an EGGoin would be the defining of standards so that the game would be fair independently of a user's lifestyle or household size.

A first standard to be defined would be related with the game's periodicity. The weekly timespan was chosen because it was considered as the minimum period to allow a trustworthy comparison between any two samples, as the day timespan, and all the timespans bellow, were thought to be too variant over time – Work days would have very different profiles from the weekend days, as an example. A week would comprise this variance and set a much more stable basis to build this game upon.

Dealing with the lifestyle and household types' variance would be a greater challenge, which would inevitably have to lead to setting the game to be built not over absolute results, but on results relative to the improvement over time. To achieve this, as the user installed one of the behaviour monitoring devices and started the game, the device, and consequently the game, would go through a preliminary stage in which no feedback would be given to the user and these entities would be focused in understanding the household's standards. Giving the example of the developed EGGY device, set in a refrigerator, this would mean the understanding of the typical number of the refrigerator's door openings, the time left opened and temperature variance. After accomplishing the measurement of these standards, the game would set an allowance to the user that, on average, would grant it to get to the end of the week and have spent exactly the allowance it was given. This allowance would then evolve every week, according to the user's behaviours over time.

This would solve the chicken and egg problem of setting the allowance or the EGGoin costs first. To implement this idea of a non-fixed, relative allowance the first step would then be the establishment of a table for the cost of EGGoins to pay per behaviour – which would be fixed. Table 28 holds these costs for the case of the current implementation, ready for a refrigerator's behavioural monitoring.

Table 28 **The EGGoin costs per behaviour of the Allowance Model.**

| Behaviour | Cost per Event [EGGoins] | Cost per Duration [EGGoins/s] | Cost Periodicity |
|---|---|---|---|
| **Refrigerator Door Opening** | 10 | 2 | - |
| **Refrigerator Set Temperature** | ( Equation 4) | - | per hour |

$$Cost[T_{Sampled}] = \begin{cases} \left(\frac{1}{|T_{Sampled}|} - \frac{1}{11}\right) \cdot 200, & 0 < T_{Sampled} \leq 11 \\ 0, & T_{Sampled} > 11 \\ 200, & T_{Sampled} = 0 \end{cases}$$

Equation 4 **Calculation of the EGGoins cost associated to a temperature sample, for the Allowance Model.**

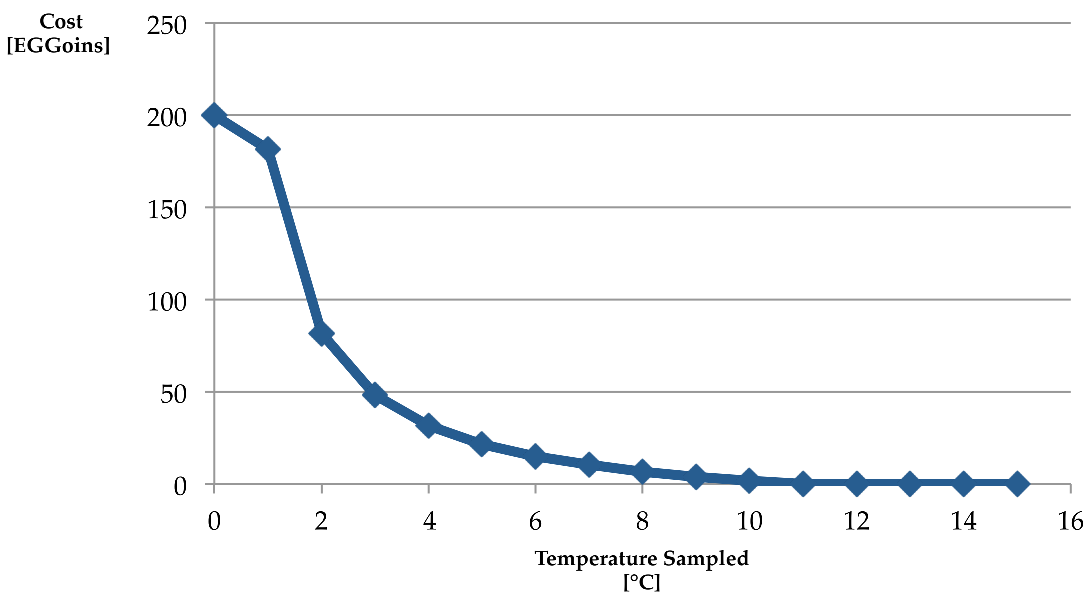



Figure 65 **Graph of the EGGoin cost per temperature sample, for the Allowance Model.**

Considering that on a particular day a certain user opened the refrigerator's door four times, and the duration of each event was respectively 2 seconds, 10 seconds, 15 seconds and 9 seconds, then on that day the user would have got to spend $4 * 10 + (2 + 10 + 15 + 9) * 2 = 112$ EGGoins from its allowance due to door opening events. If on that same day the user's refrigerator would have maintained a stable temperature, set for example at 7°C, then the user would have had to use $24 * \left(\left(\frac{1}{7} - \frac{1}{11}\right) \cdot 200\right) = 240$ EGGoins. In total, the user would have had to spend 352 EGGoins on that day.

The EGGoin allowance would then be set according to these pre-set costs and the average behaviour acknowledged by the device from the preliminary stage. Considering the same user and that its average behaviour, learnt from the preliminary stage, corresponded to the day just depicted, meaning that on average the user would open the refrigerator door 4 times for a total time of 36 seconds, and that the average temperature was 7°C. As this would lead to an EGGoin consumption of 352, then the allowance would be set as $7 * 352 = 2464$ EGGoins, seven times the expected EGGoin consumption per day of average behaviour. The only way for the user to get to the EGGoin balance at the end of a week and still have a portion of the allowance available, to be added to the EGGoin bank, would be if some improvement over the average behaviour would have happened on any day during that week. Larger improvements would mean a larger portion of the weekly allowance available on the EGGoin balance moment to be added to the EGGoin bank. The average behaviour used to compute the EGGoin allowance would be updated every week, at the end of each one.

As it was stated throughout this work, part of the objective with setting up a game and establishing a single metric to compile behaviour would be the facilitation of the comparison between users and their own comprehensibility of their behaviour and how much could it be improved. To accomplish these goals it was considered as fundamental to develop ranking boards, as these would allow a quick take on any user's improvement, by comparison with the other users', and, when set at the EGGoin rewarding system, would also bring a healthy communitarian competition for rewards.

These rankings would be established around the number of EGGoins saved from the allowance and consequently collected to their EGGoin bank every week – As so, around the improvement on behaviour, and not on absolute behaviour, which would more easily filter the households' type, size and occupant lifestyle influence on the results that could turn a communitarian game to be unfair for some. Three main timespans were to be considered – Weekly, monthly and overall. At the end of the week the users would get an extra amount of EGGoins flowing directly to their EGGoin bank depending on their position in the weekly ranking. The same would happen monthly according to the EGGoins collected from the allowance during the weeks of that month. The overall would be considered on a three-month basis and would have the particularity of never being flushed – As it would relate to the total improvement done by each user since the first moment it joined the community. Every three months this ranking would be checked and an extra amount of EGGoins would be delivered to a user's bank depending on the user's position in this ranking.

Figure 66 illustrates the granting of EGGoins on a week basis.

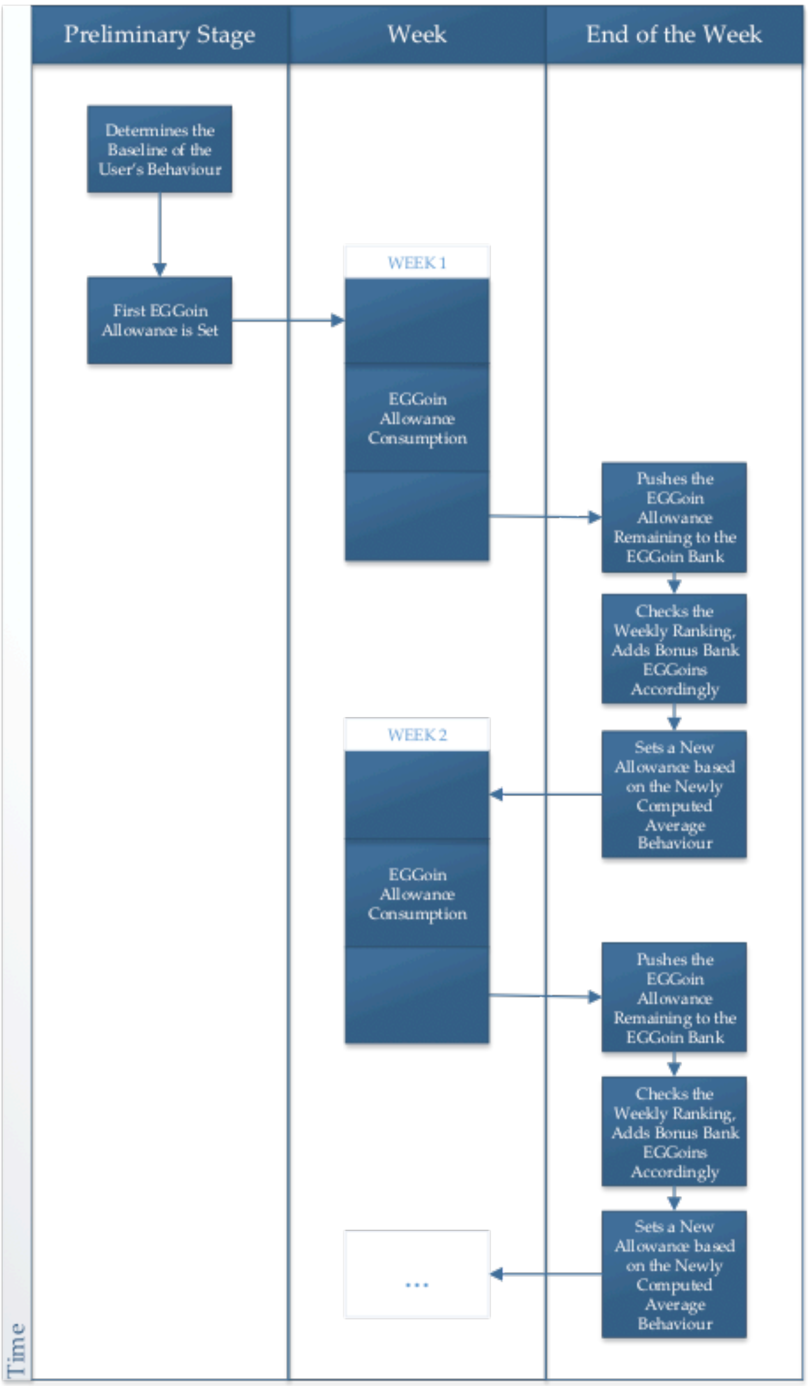



**Figure 66** Flow chart of the granting of EGGoins on a week basis.

The EGGoins collected at the EGGoin bank, and only these, would be available to use on an EGGoin store. Two major types of offers would be presented – Game related and reward related offers.

The game related offers would allow the user to purchase artefacts to help strategically within the game. These artefacts, called Powerups, would allow a user to have temporary discounts on EGGoin costs for itself, to temporarily inflate the EGGoin costs for others or to protect itself from these Powerups. If well used, these EGGoin investments should grant the user a way to bank more EGGoins on a particular week. A first list of Powerups was considered, which is shown below at Table 29. The number of EGGoins required to purchase these Powerups would have to go through trials in order to guarantee a good compromise with their respective outcome, and also the fairness of the game.

**Table 29** **Examples of EGGoin purchasable Powerups.**

| Powerup Name | Target | Action | Cost [EGGoins] |
|---|---|---|---|
| **Hot Jelly** | Other User | Decreases the Temperature 2°C for 1h, as a way to compensate the compressor over-duty for a virtual hot object inside the refrigerator; | 30 |
| **Party Time** | Self User | No door opening related costs are considered for a day; | 200 |
| **Shell Shield** | Self User | The next foreigner Powerup which targets the user will not be considered (The protection is invisible to other users); | 100 |
| **Peekaboo** | Other User | Virtually opens the refrigerator door of a target user for 5 seconds; | 20 |
| **Super Peekaboo** | Other User | Virtually opens the refrigerator door of a target user for 20 seconds; | 60 |
| **Mighty Nothing** | Other User | Does nothing if the targeted user is unprotected. But, as an inverse Trojan horse, it destroys a Shell Shield if the targeted user is protected with one; | 20 |

The user may also use the EGGoins to redeem rewards presented by third party entities at this store. This extrinsic type of motivation was seen as a very valuable complement to the mostly intrinsic motivation brought by the game setup. With it a cashback of the technology could be more easily calculated and achieved, which would inevitably lead to a less resilient distribution of the technology among households – Which would facilitate the project's objective of having a relevant harvesting of a region's domestic consumption patterns.

This model was considered as a valid option that could grant an extended engagement if the first days of plain and silent monitoring by the device were not contemplated. But this initial setup period was thought to be demotivating to the user, and consequently harmful to the further engagement. This could be solved by simply setting a standard, pre-determined average behaviour to be considered as the user's baseline, on its on-boarding in the game. But it was also understood that the focus on the punishment of behaviours, as that associated to the EGGoin costs and their consumption of an allowance, was considered as a bad practice by psychology-based research, even for this kind of case in which an educational purpose is at stake. Oppositely, a model to praise the good achievements was to be sought.

This would lead to the development of an alternative model, which would later be defined as the Energy Model.

#### 3.2.2.2 The Energy Model

The Energy Model is set over the most traditional gamification standards – Incremental points and levels. But the fact that some metric other than incremental points would be needed to aggregate all the influence of behaviour in real-time, which could be more or less positive, would again disrupt the classic view over these implementations. As the psychology-based research strongly suggested that the main metric should be incremental, what was left to use as the differentiator between good and bad achievements would be its derivative – How fast these points would grow.

This idea led to the design of a gauge, divided between seven discrete levels, that would be called the EGGnergy Meter. The filling of this gauge would determine the growth rate of the points.

There would be two contributions to the filling of the EGGnergy Meter – One related to the refrigerator's door openings and another to the set temperature.

While the refrigerator's door would be kept closed the EGGnergy Meter would be filled according to a certain function to be designed and, consequently, the growth rate of the points would be increasing. If a door opening would happen, the gauge would decrease its level for an amount corresponding to the duration of that opening, and the points' growth would slow down. Six of the seven levels of the gauge would be under these rules.

The remaining level of the seven total levels would be dedicated to the temperature monitoring. This level would be filled whenever the last temperature reading would be under upper and lower thresholds. While off this interval, the gauge would be limited to a top level of 6.

Figure 67 illustrates the evolution of the EGGnergy Meter for a specific use case which is depicted in the following paragraph.

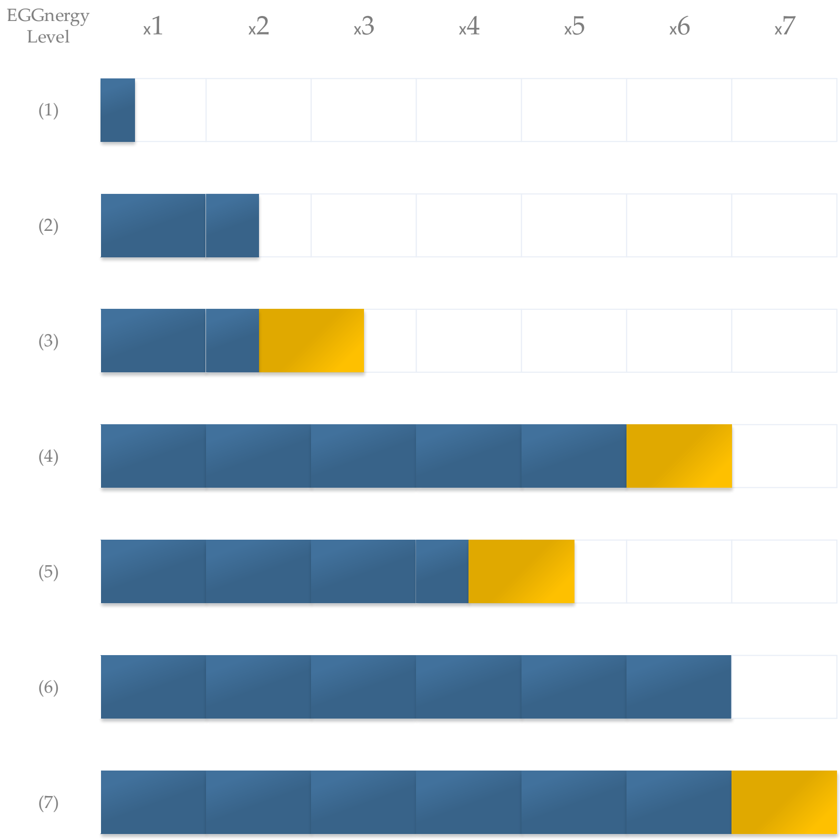



**Figure 67** **Evolution of the EGGnergy Meter filling for a specific use case depicted below.**

As the device is put inside the refrigerator for a first time it will be out of EGGnergy. This would also happen later if a door opening event would have such a duration that all the current EGGnergy would be consumed. (1) and (2) illustrate this situation in which the EGGnergy Meter is initially empty and, as the refrigerator door is kept closed, the meter starts to get filled. In (2) the EGGnergy level 2 is reached. Until this point the temperature would have been outside the boundaries that would set it to be ideal. In (3) the temperature would have reached the ideal interval, and with that an extra level of EGGnergy would be added – This contribution of the temperature on the device's EGGnergy is identified as the yellow block on the depicted diagram. As the refrigerator's door would be still left closed the device's EGGnergy would continue to grow. In (4) the EGGnergy level would have reached the level 6. (5) depicts a door opening, and with that, a decrease of the portion of the EGGnergy illustrated in blue, proportional to the duration of the door opening. After this event the device's EGGnergy would recover its pace and start to grow again. (6) illustrates the EGGnergy reaching level 6 again, but in the mean time, the device would have detected that the temperature would have slipped outside the ideal boundaries. This would make the bonus level of EGGnergy related to the temperature monitoring to be disabled. The only way to reach the maximum level 7 would be if the temperature would then again be detected to be under the boundaries of the ideal, as depicted in (7).

The preceding description defines the basic idea behind the Energy Model – A gauge influenced by behaviour that sets incremental points to grow faster or slower. But questions arise about the implementation of this idea, specially regarding how is the increment in the points' growth rate correlated to the discrete levels of EGGnergy, and about the filling rate of the gauge while a refrigerator's door is kept closed, as the combination of these two variables should lead to a non-linear behaviour as a way to guarantee that the users' several performance levels within the game would be well stratified.

The decision relied upon setting a linear correlation between each EGGnergy level and the effect on the increment of the points' growth rate and bring the non-linearity to the filling rate of the gauge. Each EGGnergy level would be set to correspond to a multiplier over a base growth rate, as it was already anticipated in Figure 67. The base growth rate to be set would have the value of one point per second. With each level acting as a multiplier, the level 2 would grant a growth rate of two points per second, the level 3 a three points per second, and so on.

The game design would get its complexity from the time of door closed needed to reach a certain level, and from the impact of a door opening on the decreasing of this level. Figure 68 shows a graph of the curve that correlates the time of door closed with the gauge's filling. The red lines separate the gauge's several discrete levels. Equation 5 shows the generic function that led to this curve, while Equation 6 shows the final parameterized result, which was achieved by setting a set of constraints to the function's limits.

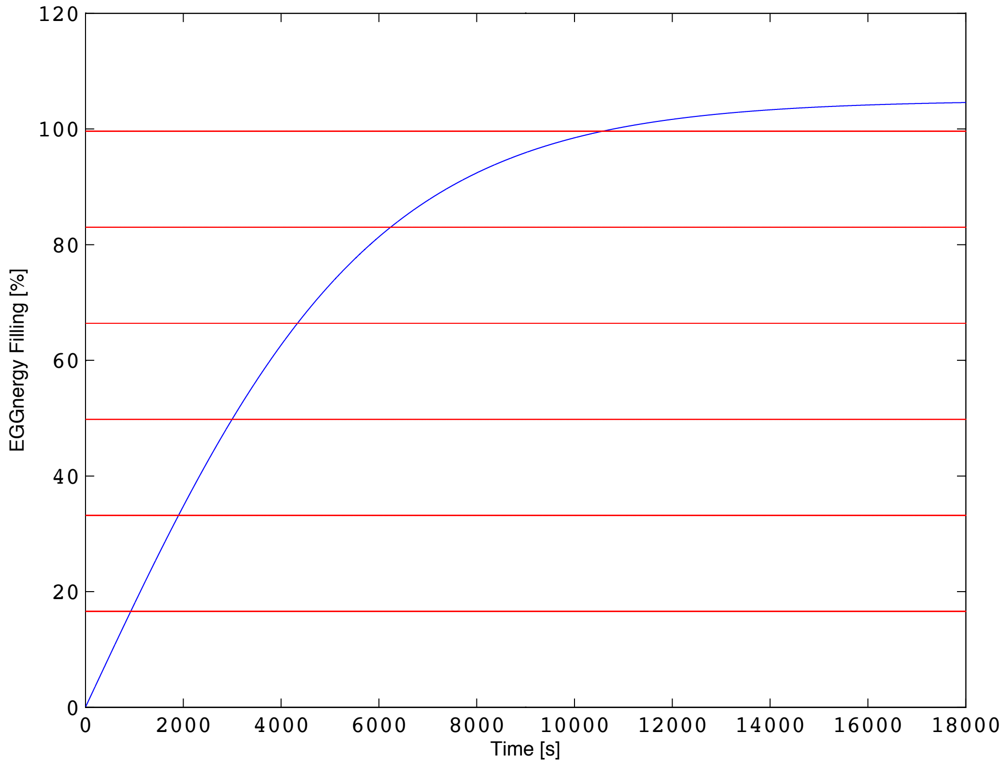



**Figure 68** **Illustration of the EGGnergy filling rate over time of door closed.**

$$EGGnergy_{[\%]} = EGGnergy_{Offset} + EGGnergy_{Offset\ Multiplier} * \left(\frac{EGGnergy_{Max}}{1 + e^{-EGGnergy_{Growth}*(t - EGGnergy_{Shift})}} - \frac{EGGnergy_{Max}}{2}\right)$$

**Equation 5** **Generic function for calculating the EGGnergy filling percentage, before parameterization.**

$$\begin{cases} EGGnergy_{Offset} = 0 \\ EGGnergy_{Offset\ Multiplier} = 1 \\ EGGnergy_{Max} = 210 \\ EGGnergy_{Growth} = 3.4385 * 10^{-4} \\ EGGnergy_{Shift} = 0 \end{cases}$$

$$EGGnergy_{[\%]} = \left(\frac{210}{1 + e^{-3.4385*10^{-4}*t}} - \frac{210}{2}\right)$$

**Equation 6** **Parameterized function for calculating the EGGnergy filling percentage.**

By inspecting this curve it is quickly understood that it would take about 10 500 seconds, roughly 3 hours, of a given refrigerator's door closed for the EGGnergy gauge to be totally filled, from zero. The 3-hour limit would be one of the constraints that would lead to the preceding parameterization. Table 30 shows the filling time of each EGGnergy level.

**Table 30** **EGGnergy level upgrade times.**

| EGGnergy Level | Filling Time |
|---|---|
| **Level 1** | 17m |
| **Level 2** | 17m |
| **Level 3** | 17m |
| **Level 4** | 23m |
| **Level 5** | 31m |
| **Level 6** | 1h10m |
| **Level 1 – Level 6** | 3h |

This curve would set the highest levels of EGGnergy to be less achievable then the first, by requiring up to 400% of the time of door closed, and the consequence would be a better stratification of the users within the game, in respect to their behaviour. The EGGnergy growth would always respect this curve, meaning that, while growing, the time of door closed required to evolve from a specific EGGnergy filling percentage to another would always be the same. For example, every time that the EGGnergy filling would find itself at 70% the time of door closed required to get to the 100% would always be 1h35m. But the decrease in this gauge due to door openings should not move alongside the same curve, because a very different range of time was to be considered and also because an inverse behaviour, in which a deflation of the filling percentage should accelerate in respect to the door opening's duration, was sought. A new curve was designed to determine the EGGnergy deflation in respect to the door-opening period. After calculating the deflation due to a certain door opening, in percentage of the EGGnergy gauge's filling, the EGGnergy gauge would recover its filling according to its growing curve, from the point relative to the filling percentage remaining after the door-opening event.

Figure 69 illustrates the deflation curve of the EGGnergy filling over time of door opening. Equation 7 and Equation 8 would describe this curve.

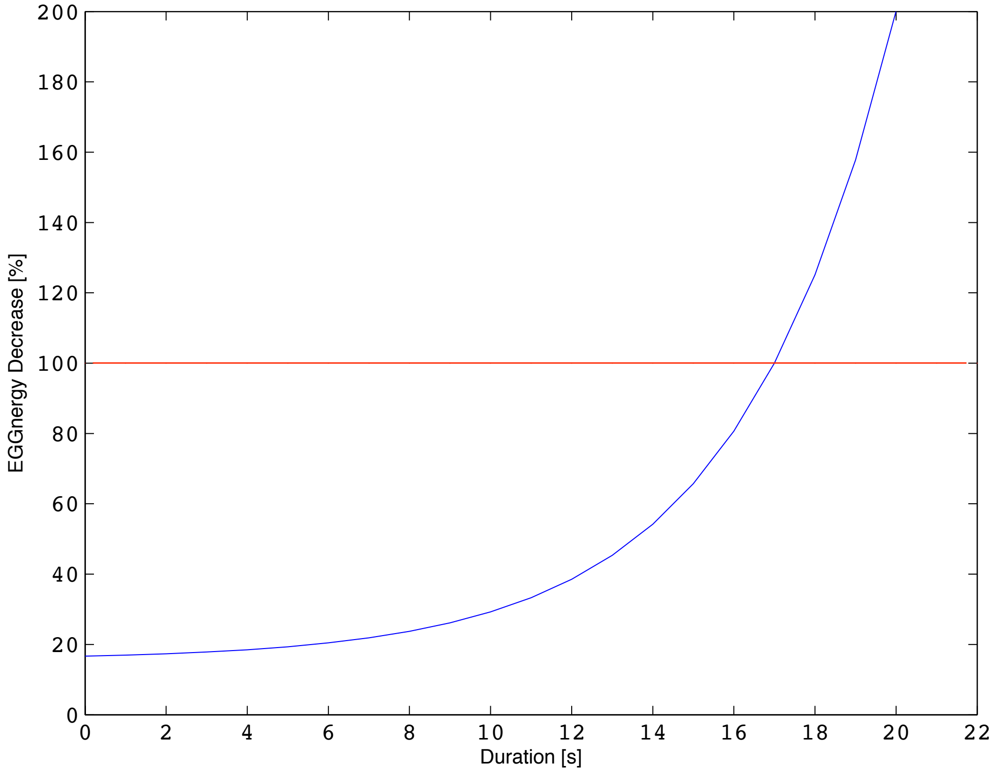



**Figure 69** **Illustration of the EGGnergy decrease over a door opening duration.**

$$EGGnergy_{Deflation\,[\%]} = \alpha^t + \beta$$

**Equation 7** **Generic function for calculating the EGGnergy deflation percentage, before parameterization.**

$$\begin{cases} \alpha = 1.298064 \\ \beta = 15.66 \end{cases}$$

$$EGGnergy_{Deflation\,[\%]} = 1.298064^t + 15.66$$

**Equation 8** **Parameterized function for calculating the EGGnergy deflation percentage.**

This parameterization was set over the constraint of having a total deflation of the EGGnergy gauge in 17 seconds. The exponential function was used as a way to penalize larger openings considerably, and separate the influence of these from that coming from the shorter ones, and with that strongly demotivating larger openings. An offset was introduced as a way to penalize every opening.

As described before, the calculated deflation would then be subtracted from the past EGGnergy filling and with that setting a new current filling which would now grow again according to the curve of Figure 68, from the point of the new filling value.

The preceding description fully details how does the increment and decrement on the points' growth rate was implemented. It would be now relevant to detail what would these points determine within the game, and specifically how would these relate to the redeemable EGGoin metric. These points could be seen as the fuel to the entire game design model being considered. One of their main purposes would be to guarantee an incremental metric that would immediately acknowledge the total effort put by the user since the on boarding. To help in this acknowledgment, the points would be stacked within levels. The user would start on level 1, with zero points, and to evolve into the next level it would have to collect an amount of 100 points. From this point forward each level would require an amount of points 1.5 times higher than the last one to evolve. For example, to close level 2 and move into level 3 the user would have to collect 1.5 times the number points that led it to level 2, namely $1.5 * 500 = 750$.

The points would also be used to set three rankings – Daily, weekly and overall rankings. These rankings would be simply set over how much points each user would be able to collect during each timespan.

EGGoins would be collected by completing achievements, which could be related to levels completed, ranking positions registered or challenges' conquered. Although, the model's design was to be completed with definitive values for specific EGGoin reward values, which was not achieved by the time of the publishing of this work.

Going up a level would grant the user an amount of EGGoins, depending on the level being achieved. This amount should scale linearly.

At the end of each day and week the rankings would be registered and EGGoins would be distributed according to the users' positions.

Challenges would set a user the chance to wage a number of banked EGGoins in favour of its own behavioural improvement or in favour or against another user's. At the end of a Challenge period a user would recoup the amount of EGGoins it put at stake, multiplied by a value determined by the specific Challenge, or it would lose the EGGoins at stake if the bet was not fulfilled. These wages would set a compromise of the user with its own improvement, if betting itself, and would bring users' to incentivise each other improvements, or set a very competitive environment, when betting in others. The specific Challenges' implementations were not closed by the time of the publishing of this document.

A special status of the EGGY called Vacations was to be considered as way to avoid rewarding users that are not habiting the house where the EGGY is Active. If no activity (e.g. door openings) would be registered for a day the EGGY would be put automatically into this status. The user could also trigger this by enabling the Vacation status with the user application. While in this status the EGGnergy boost level would be put to zero, and the points would not grow on door closed. To take the EGGY out of its Vacations, the user would have to open the refrigerator's door.

This model would be the one chosen to be run under a first pilot stage, mainly because it wouldn't require any knowledge about average behaviour in advance, as a first pilot would be run exactly with the primary purpose of getting information about typical patterns of behaviour.

5

# Pilot Project

## 5.1 Objectives

After reviewing documentation about behavioural change, its impact on residential energy efficiency and the tools to accomplish it, and consequently implementing a connected device, supported by a *gamified* web application, to promote the residential energy efficiency awareness, a pilot test of this technology was intended to harvest relevant data regarding the energy efficiency related behaviours and the engagement towards energy savings from a set of users, which would later be used to validate the prospective impact of this project. A collection of objectives was set for this pilot test:

1. Extrapolate the share of the households with WiFi connectivity installed in which the device is completely functional, without any constraint.
2. Validate the device's expected lifespan in two levels – Technical, as the power-supply and the rest of the hardware is to be tested under operation conditions, and Usage, as in the period in which the user is actively engaged with the device.
3. Acknowledge behavioural diversity towards the refrigerator usage between households with similar profiles, but also a common baseline within those groups of households.
4. Acknowledge non-random behaviour variations towards the refrigerator usage within a single household. Validate that the device contributes to improve these behaviours over time.

5. Validate empirically that the points system designed is fairly beneficial to the best performing users and that it can motivate the worst performing users to improve their behaviour.

## 5.2 Setup

This pilot would be dimensioned for a set of 100 participants, as the validation inherent at the previously described objectives would require a sample within this order of magnitude. However it was decided that prior to conducting the full-scale pilot, a smaller test should be run in order to take preliminary conclusions that might lead to fine tuning the setup and objectives of the main 100-unit pilot. This smaller test would be conducted with 12 participants. By the time of the publishing of this document, only preliminary results from the 12-unit pilot would be available for analysis. This section would then present data from and conclude over these preliminary results of a 12-unit pilot. This batch would contemplate 11 households and 1 workspace.

Each participant was given an EGGY device and access to the EGGY Yolk – The dashboard to keep up with the EGGY's reports and its position at a communitarian competition, available as an iOS or Android mobile application.

Each participant was inquired through a survey about its household composition, common habits and general knowledge towards energy efficiency at home. Table 31 shows a resume of the characterization of the households under this test. Four levels of analysis would be further performed, based on the households' size, composition, average occupancy hours per day on workdays and type of setting, respectively. For each of these levels, groups would be formed. Regarding the households' size four groups would be considered, representing households' with 1 to 4 members, respectively. The households' composition would lead to three groups, representing the household's with children, those with retired or unemployed members and finally those with none of the above. The third level would consider two groups, one composed by those households with 6 or less occupancy hours, and another with those that exceed this number. Finally the last level would also consider two groups, one composed by all the households, through its average behaviour, and another composed by the single workspace presented in this study. Patterns of these groups' behaviour would then be analysed and confronted together. Figure 70 illustrates these levels and their groups compositions.

**Table 31** Resume of the profile of the households under the preliminary pilot.

| House-hold's ID # | EGGY Owner Age | EGGY Owner Genre | Household's size | Household's Number of Children | Household's Number of Retired or Unemployed People | Household's Avg. Number of Hours per Day with Active Occupants on Workdays |
|---|---|---|---|---|---|---|
| **1** | 26 | F | 3 | 1 | 0 | 5 |
| **2** | 28 | M | 2 | 0 | 0 | 6 |
| **3** | 32 | M | 2 | 0 | 0 | 4 |
| **4** | 27 | M | 2 | 0 | 0 | 5 |
| **5** | 26 | F | 1 | 0 | 0 | 5 |
| **6** | 46 | M | 4 | 2 | 0 | 13 |
| **7** | 48 | M | 4 | 2 | 0 | 6 |
| **8** | 26 | M | 3 | 0 | 1 | 12 |
| **9** | 27 | M | 3 | 0 | 1 | 8 |
| **10** | 31 | M | 2 | 0 | 0 | 5 |
| **11** | 25 | M | 3 | 0 | 0 | 5 |

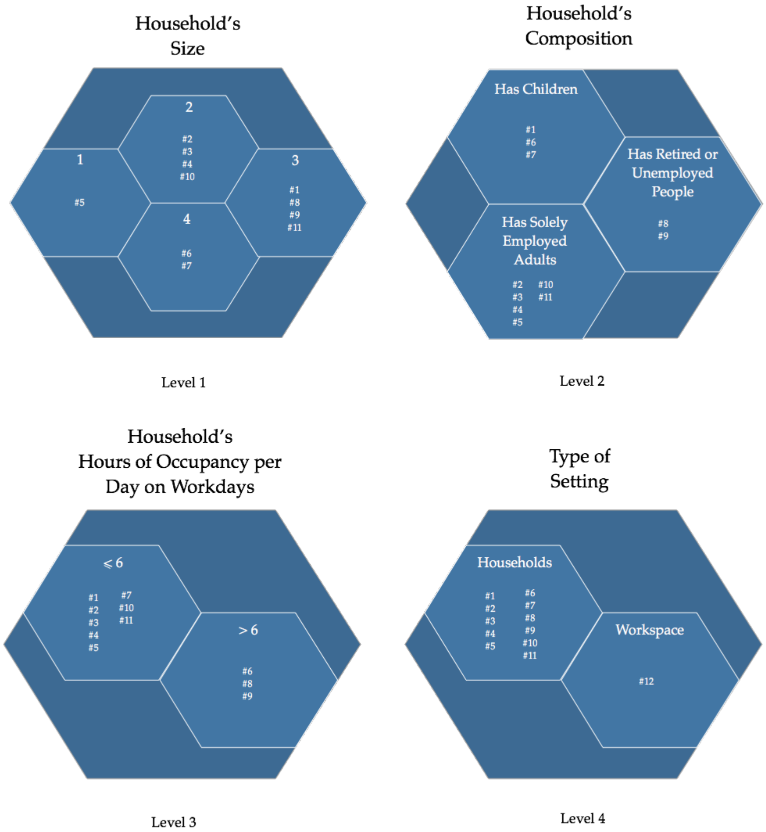



**Figure 70** Illustration of the levels of analysis considered for this study.

It is relevant to state that all the participants work at a same institution, the innovation department of an energy provider company. The following figures further characterize the households under this test.

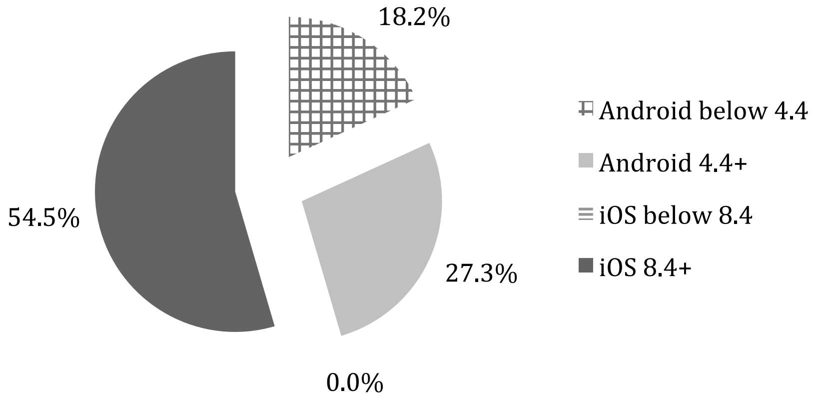



**Figure 71** **Shares of the mobile OS's used by the EGGY owners.**

All the participants owned a smart-phone.

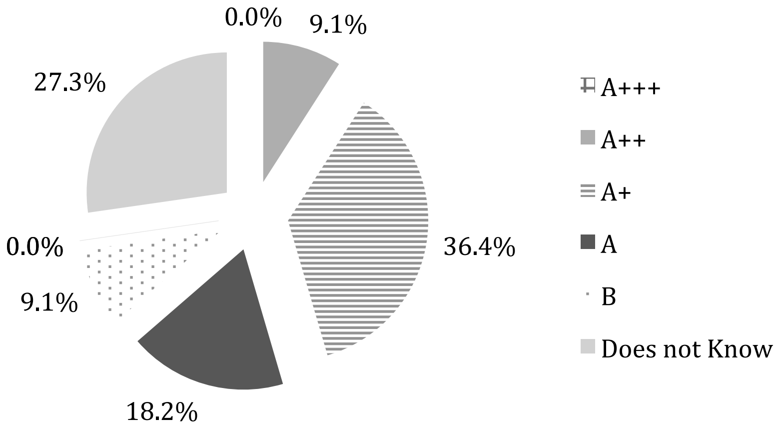



**Figure 72** **Shares of the classes of refrigerators owned by the participants.**

Most of the participants were able to tell immediately the class of their refrigerator (72.7%). The most common class in this sample is the A++. The participants were also requested to give their perception about the average daily consumption expected by their refrigerator, in kWh. None of the participants were able to answer with an approximate value.

Regarding their household's energy consumption, only one participant was able to point to an average value of its household's monthly energy consumption in kWh, with the answer of 120 kWh. 9 (81.8%) revealed that they never had any of their appliances plugged in to any type of energy consumption reading device. Nevertheless, when inquired about the perception of their appliances energy consumption, and on their concern to it, on a scale to 1 to 10 most participants answered 8 or above.

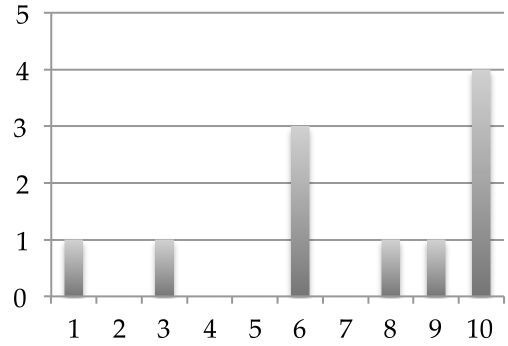



**Figure 73** **Number of answers per self-determined level of knowledge regarding the participant's household's energy consumption.**

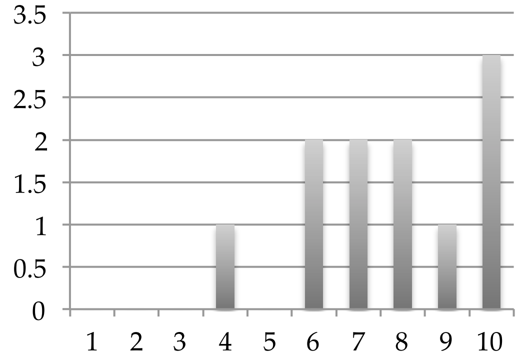



**Figure 74** **Number of answers per self-determined level of concern regarding the participant's household's energy consumption.**

10 (90.9%) of the 11 enquired families stated to have a sense of the impact of their personal behaviour on this metric. Most participants evaluated their behaviour towards energy efficiency at home as "Good". The total number of the participants stated to be concerned with the education towards energy efficiency.

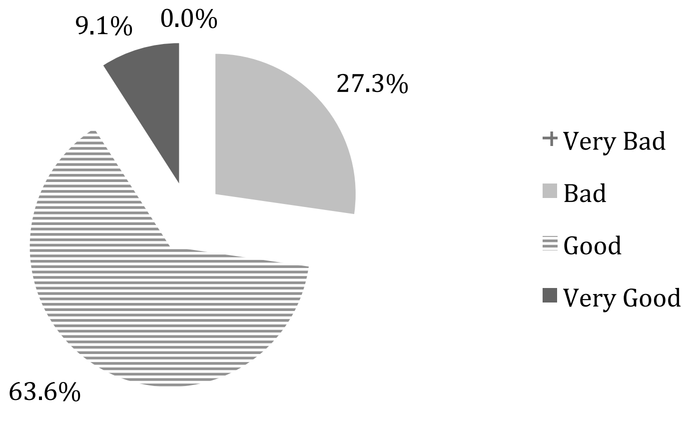



**Figure 75** **Shares of the participants' self-determined quality of behaviour towards energy efficiency at home.**

Finally most participants stated that they would be willing to pay between 30€ to 100€ for devices that could contribute their household's energy efficiency awareness. It is relevant to point out that the participants knew about EGGY's current functionalities before the conduction of this survey.

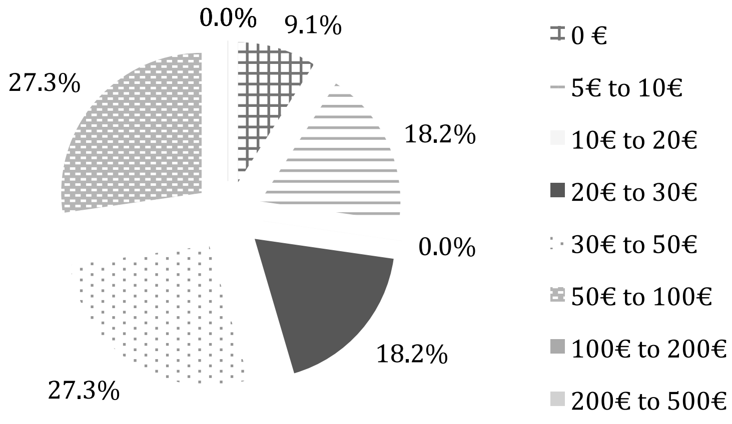



**Figure 76** **Shares of the participants' willingness to pay for energy efficiency awareness devices.**

## 5.3 Preliminary Results

These results were gathered from January 1st to March 15th of the same year, 2016.

All the levels of the results considered include a table where the major metrics regarding usage patterns towards a refrigerator are presented, and confronted among the groups of the given level, through a table.

Five metrics were considered for this analysis – The number of the refrigerator's door openings per day, the time opened per opening, the variation of the time opened per opening, the temperature, and the variation of the temperature. For each of these metrics, the maximum, average, and minimum values would be determined and presented. For the case of the deviation (Δ) variables these would be calculated by determining the standard deviation (σ) within the maximums, averages and minimums of all the days of the sample, respectively.

The method used for processing this data presented at this table is described by four phases – Data Grabbing, Daily Aggregation, Daily Sorting and Overall Aggregation.

At the Data Grabbing phase the boundaries of the data to grab are set and the data that fits in those boundaries is retrieved from the database. The boundaries are set by two dates – Initial and final dates – and a list of households.

At this implementation the following Daily Aggregation phase is virtual, because the data retrieved from the database would already represent daily information (calculated daily and stored as a Data Frame structure by the web platform, as depicted on Chapter 4). But at this point it should be noted that the day is the basic unit for further calculations and analysis. The reader should picture the outcome of this phase as a bag full of cards with daily information, in which the household to which that day's data belongs to is simply an attribute of that given card, and not a key value.

With every day of the time interval set of every household at a same bag, a sorting process to extract the days with distinct values (as the day with the highest number of openings, or the day in which the largest opening duration happened, for example, of the whole group) happens at the Daily Sorting phase.

Finally, at the last phase, all the daily cards are combined in one single card holding aggregate information about them all. This phase is named as Overall Aggregation.

The Daily Sorting and Overall Aggregation are the phases that provided the following information presented at this Preliminary Results. Table 34 illustrates their contribute.

**Table 32** **Labelling of the variables under test and the processing phase from which they are generated.**

| Variables | | Description | Generation Phase |
|---|---|---|---|
| # Openings /day | **Max.** | Maximum number of door openings on a day; | Daily Sorting |
| | **Avg.** | Average number of door openings per day; | Overall Aggregation |
| | **Min.** | Minimum number of door openings on a day; | Daily Sorting |
| Opening Duration | **Max.** | Maximum opening duration on a day; | Daily Sorting |
| | **Avg.** | Average opening duration; | Overall Aggregation |
| | **Min.** | Minimum opening duration on a day; | Daily Sorting |
| Δ Opening Duration | **Max.** | Standard deviation among maximums; | Overall Aggregation |
| | **Avg.** | Standard deviation among averages; | Overall Aggregation |
| | **Min.** | Standard deviation among minimums; | Overall Aggregation |

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| | | | |
|---|---|---|---|
| Temp | Max. | Maximum temperature registered on a day; | Daily Sorting |
| | Avg. | Average temperature; | Overall Aggregation |
| | Min. | Minimum temperature registered on a day; | Daily Sorting |
| Δ Temp | Max. | Standard deviation among maximums; | Overall Aggregation |
| | Avg. | Standard deviation among averages; | Overall Aggregation |
| | Min. | Standard deviation among minimums; | Overall Aggregation |

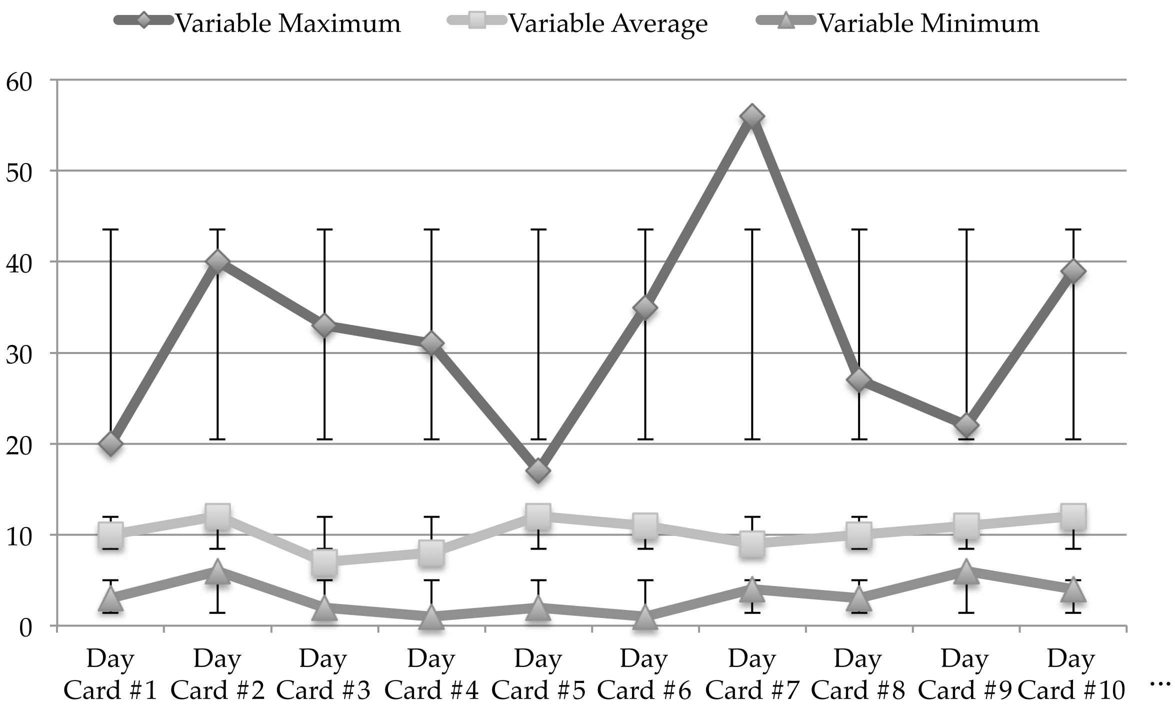


**Figure 77** **Illustration of the standard deviations considered in this study, considering a generic variable.**

Figure 77 is shown to facilitate the perception of what the standard deviations referred before represent in this study, for a generic variable.

For each level of results, compiled information about the households belonging to a specific group is also presented. The intention is provide information that may allow verifying the level of variance within a group.

On level 4 besides comparing setting types it is further presented the generic information about all the households considered in this study (Overall Aggregation results), which also considers a wrap-up of the game-related metrics.

To mine this behavioural information from the data previously harvested by the EGGY device and stored at the web platform's database, and to make it ready for instant visualization and analysis, a web-based tool, named as the EGGY Yolk Control Panel, would be developed. This tool would also be put under validation, as it would be necessary to guarantee that consistent and reliable information would be generated through it.


**Figure 78** **Illustration of a segment of the EGGY Yolk Control Panel.**

### Level 1 – Household's Size

This level of the results would consider four groups that would represent households' with 1 to 4 members, respectively.

**Table 33** **Behaviour patterns towards the refrigerator usage of the groups considered in the level 1, regarding the households' sizes.**

| | Household's Size ➔ | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| # Openings /day | Max. | 20x | 18x | 32x | 35x |
| | Avg. | 6x | 8x | 18x | 18x |
| | Min. | 1x | 2x | 5x | 2x |
| Opening Duration | Max. | 20m 36s | 7h 16m 29s | 11m 09s | 22m 34s |
| | Avg. | 32s | 15m19s | 16s | 50s |
| | Min. | 2s | 2s | 3s | 2s |
| Δ Opening Duration | Max. | ± 4m 21s | ± 1h 59m 52s | ± 2m 49s | ± 6m 10s |
| | Avg. | ± 54s | ± 29m 1s | ± 12s | ± 42s |
| | Min. | ± 4s | ± 3s | ± 2s | ± 1s |
| Temp | Max. | 10.8°C | 11.5°C | 9.6°C | 11.4°C |
| | Avg. | 6.1°C | 6.4°C | 6.9°C | 9.2°C |
| | Min. | 4.0°C | 2.9°C | 5.9°C | 4.9°C |
| Δ Temp | Max. | ± 0.8°C | ± 2.1°C | ± 1.2°C | ± 0.9°C |
| | Avg. | ± 0.5°C | ± 2.1°C | ± 0.8°C | ± 0.9°C |
| | Min. | ± 0.6°C | ± 2.1°C | ± 0.6°C | ± 1.0°C |

**Table 34** **Average behaviour patterns towards the refrigerator usage between one of the groups considered in the level 1, regarding households with two members.**

| Household's ID # ➔ | 2 | 3 | 4 | 10 |
|---|---|---|---|---|
| **Nr. Openings/day** | 8x | 18x | 10x | 9x |
| **Opening Duration** | 15m 19s | 1h 2m 17s | 31s | 21s |
| **Δ Opening Duration** | ± 29m 1s | ± 12m 59s | ± 61s | ± 37s |
| **Temp** | 6.4°C | 7.5°C | 5.4°C | 6.4°C |
| **Δ Temp** | ± 2.1°C | ± 1.0°C | ± 1.1°C | ± 0.6°C |

### Level 2 – Household's Composition

This level of the results would consider three groups that would represent households' with children, with retired or unemployed members, and those with solely active adults, respectively.

**Table 35** Behaviour patterns towards the refrigerator usage of the groups considered in the level 2, regarding the households' compositions.

| Household's Composition ➔ | | Has Children | Has Retired or Unemployed People | Has Solely Employed Adults |
|---|---|---|---|---|
| # Openings /day | Max. | 32x | 32x | 26x |
| | Avg. | 18x | 13x | 10x |
| | Min. | 5x | 1x | 1x |
| Opening Duration | Max. | 11m 09s | 26m 42s | 18m 40s |
| | Avg. | 16s | 48s | 51s |
| | Min. | 3s | 3s | 2s |
| Δ Opening Duration | Max. | ± 2m 49s | ± 7m 14s | ± 5m 55s |
| | Avg. | ± 12s | ± 52s | ± 1m 23s |
| | Min. | ± 2s | ± 3s | ± 6s |
| Temp | Max. | 9.6°C | 11.2°C | 9.3°C |
| | Avg. | 6.9°C | 8.5°C | 6.6°C |
| | Min. | 5.9°C | 5.9°C | 5.1°C |
| Δ Temp | Max. | ± 1.2°C | ± 1.4°C | ± 1.0°C |
| | Avg. | ± 0.8°C | ± 1.3°C | ± 0.7°C |
| | Min. | ± 0.6°C | ± 1.2°C | ± 0.6°C |

**Table 36** Average behaviour patterns towards the refrigerator usage between one of the groups considered in the level 2, regarding households with children in their composition.

| Household's ID # ➔ | 1 | 6 | 7 |
|---|---|---|---|
| **Nr. Openings/day** | 18x | 27x | 18x |
| **Opening Duration** | 16s | 16s | 50s |
| **Δ Opening Duration** | ± 12s | ± 12s | ± 42s |
| **Temp** | 6.9°C | 6.5°C | 9.2°C |
| **Δ Temp** | ± 0.8°C | ± 0.4°C | ± 0.9°C |

### Level 3 – Household's Occupancy

This level of the results would consider two groups that would represent households' that when inquired about the average workday occupancy of their households (considering only active hours awake) answered with 6 or less hours and more than 6 hours, respectively.

**Table 37** **Behaviour patterns towards the refrigerator usage of the groups considered in the level 3, regarding the households' occupancy.**

| Household's Occupancy ➔ | | ≤ 6 | > 6 |
|---|---|---|---|
| # Openings /day | Max. | 26x | 32x |
| | Avg. | 10x | 13x |
| | Min. | 1x | 1x |
| Opening Duration | Max. | 18m 40s | 26m 42s |
| | Avg. | 52s | 49s |
| | Min. | 2s | 3s |
| Δ Opening Duration | Max. | ± 5m 55s | ± 7m 14s |
| | Avg. | ± 1m 23s | ± 52s |
| | Min. | ± 2s | ± 3s |
| Temp | Max. | 9.3°C | 11.2°C |
| | Avg. | 6.6°C | 8.5°C |
| | Min. | 5.1°C | 5.9°C |
| Δ Temp | Max. | ± 1.0°C | ± 1.4°C |
| | Avg. | ± 0.7°C | ± 1.3°C |
| | Min. | ± 0.5°C | ± 1.2°C |

**Table 38** **Average behaviour patterns towards the refrigerator usage between one of the groups considered in the level 2, regarding households with solely employed adults in their composition.**

| Household's ID # ➔ | 1 | 2 | 3 | 4 | 5 | 7 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|
| Nr. Openings/day | 18x | 8x | 18x | 10x | 6x | 18x | 9x | 10x |
| Opening Duration | 16s | 15m 19s | 1h 2m 17s | 31s | 32s | 50s | 21s | 52s |
| Δ Opening Duration | ± 12s | ± 29m 1s | ± 12m 59s | ± 61s | ± 54s | ± 42s | ± 37s | ± 1m 23s |
| Temp | 6.9°C | 6.4°C | 7.5°C | 5.4°C | 6.1°C | 9.2°C | 6.4°C | 9.3°C |
| Δ Temp | ± 0.8°C | ± 2.1°C | ± 1.0°C | ± 1.1°C | ± 0.5°C | ± 0.9°C | ± 0.6°C | ± 1.0°C |

### Level 4 – Setting Type & General Overview

This level of the results would consider two groups that would oppose the total combined result of all the households with that of the only workspace that was part of this study. Further data is presented about the combined results of all the households.

**Table 39** **Behaviour patterns towards the refrigerator usage of the groups considered in the level 3, regarding the households' occupancy.**

| | Setting Type ➔ | Households | Workspace |
|---|---|---|---|
| # Openings /day | Max. | 32x | 70x |
| | Avg. | 18x | 40x |
| | Min. | 5x | 1x |
| Opening Duration | Max. | 11m 9s | 32m 04s |
| | Avg. | 16s | 24s |
| | Min. | 3s | 1s |
| Δ Opening Duration | Max. | ± 2m 49s | ± 7m 20s |
| | Avg. | ± 12s | ± 15s |
| | Min. | ± 2s | ± 6s |
| Temp | Max. | 9.6°C | 12.8°C |
| | Avg. | 6.9°C | 6.5°C |
| | Min. | 5.9°C | 4.8°C |
| Δ Temp | Max. | ± 1.2°C | ± 1.1°C |
| | Avg. | ± 0.8°C | ± 0.8°C |
| | Min. | ± 0.6°C | ± 0.8°C |

**Table 40** **Meals usually taken at home by at least one member of a household (listed with the Household ID #).**

| Meal | Workdays | Weekends |
|---|---|---|
| **Breakfast** | All; | All except ID #: 4; |
| **Morning Snack** | None; | ID #: 1; |
| **Lunch** | ID #'s: 1, 6, 9; | All except ID #'s: 3, 4, 7; |
| **Afternoon Snack** | ID #'s: 6, 9, 11; | ID #'s: 1, 2, 5, 10; |
| **Dinner** | All; | All except ID #: 4; |
| **Late Snack** | ID #'s: 1, 7, 9; | ID #'s: 1, 7, 9; |


**Figure 79** **Representation of the number of households that usually have a particular meal taken at home by at least one of its members.**

Through the EGGY Yolk Control Panel, the average values of door openings and temperature per each period of 15 minutes of the day, for all the households and considering all their reported data between January 1st and March 15th, were determine. The results are shown in the following figures Figure 80 to Figure 83, divided between Late Hours, Morning, Afternoon and Evening.

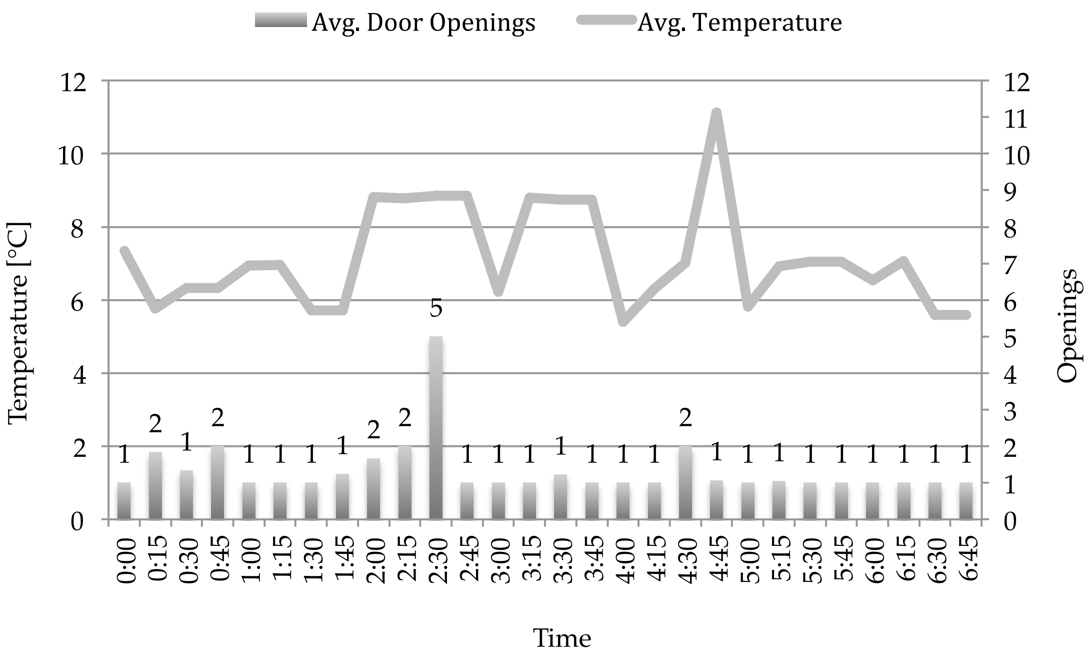


**Figure 80** **Households' average temperature and door openings per 15 minute periods during LATE HOURS.**

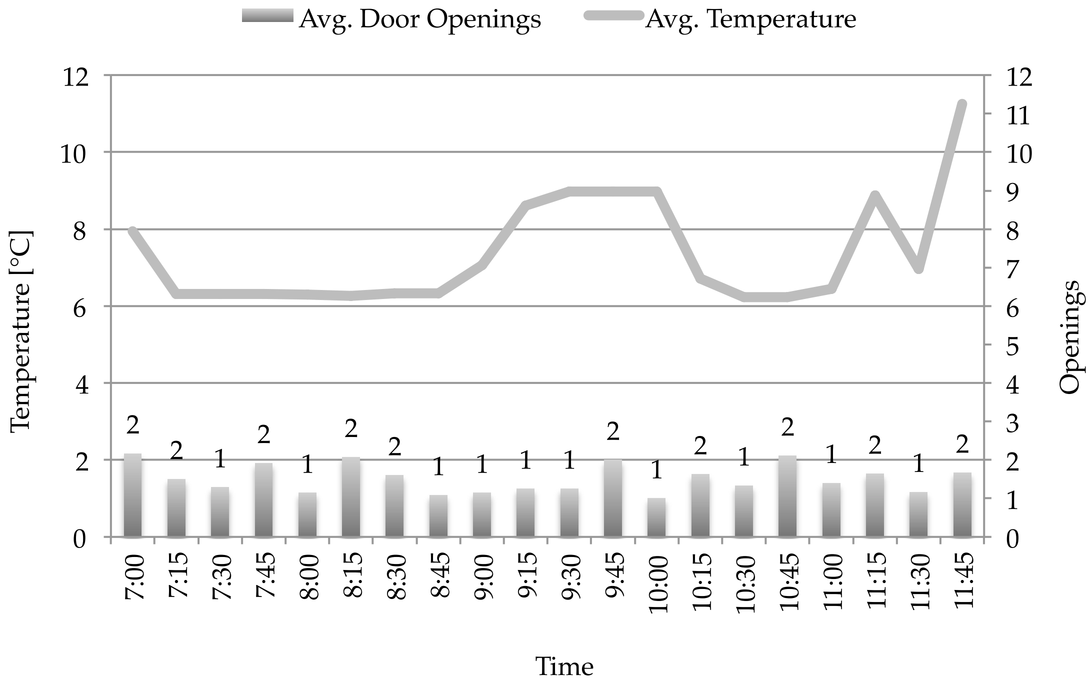


**Figure 81** **Households' average temperature and door openings per 15 minute periods during the MORNING.**

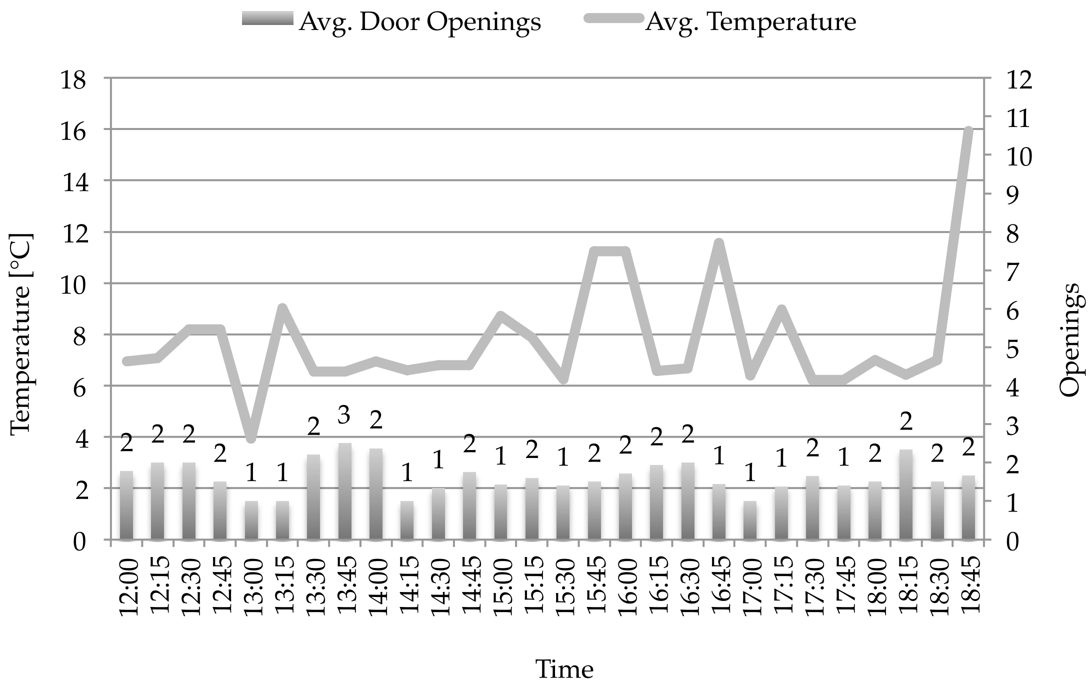


**Figure 82** **Households' average temperature and door openings per 15 minute periods during the AFTERNOON.**

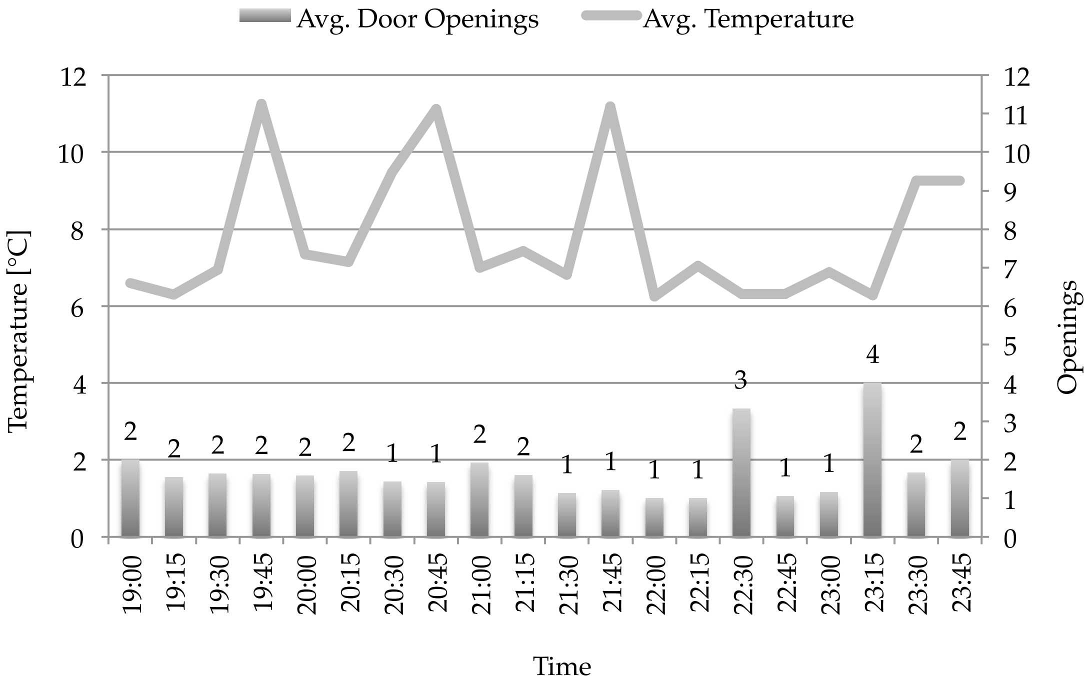


**Figure 83** **Households' average temperature and door openings per 15 minute periods during the EVENING.**

The same analysis was performed for the workspace, as shown in figures Figure 84 to Figure 87.

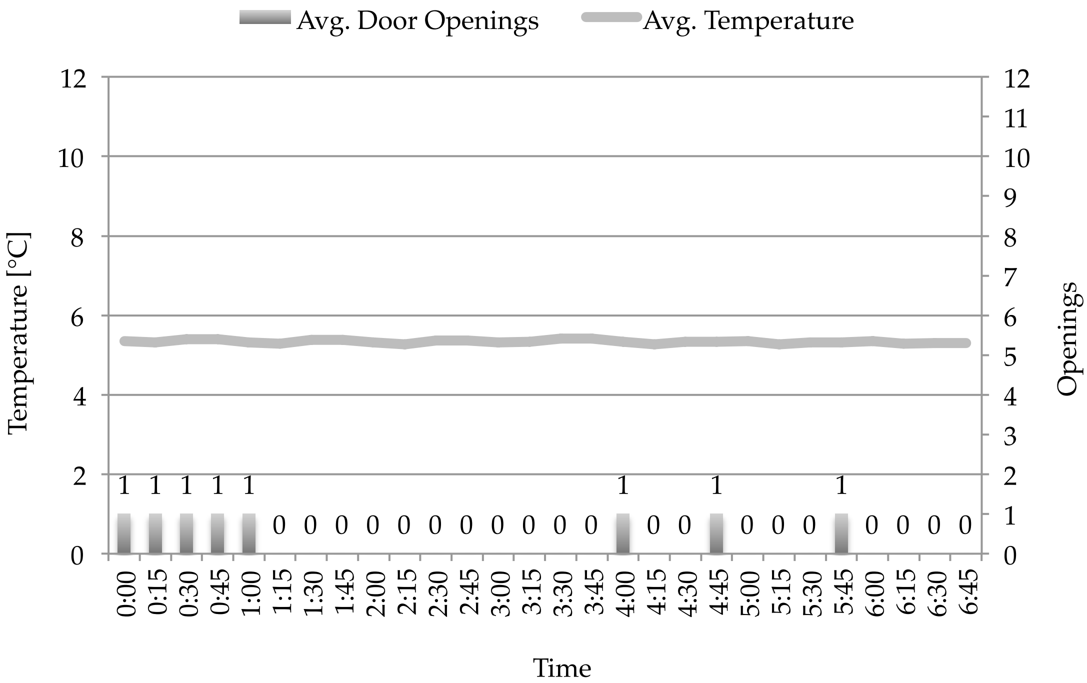


**Figure 84** **Workspace's average temperature and door openings per 15 minute periods during LATE HOURS.**

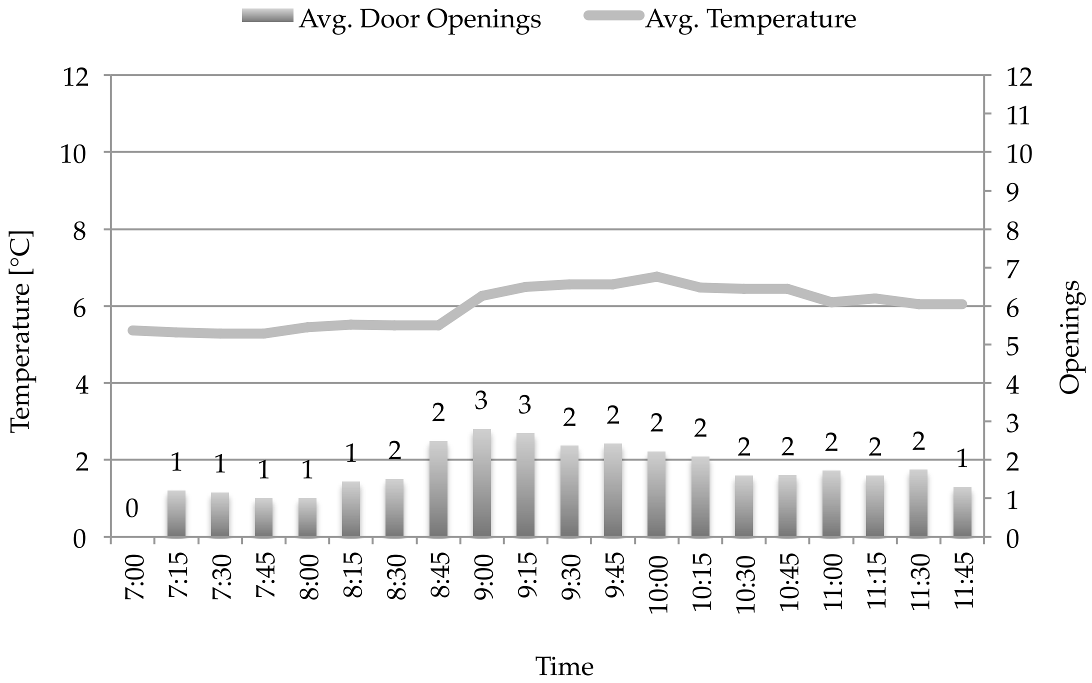


**Figure 85** **Workspace's average temperature and door openings per 15 minute periods during the MORNING.**

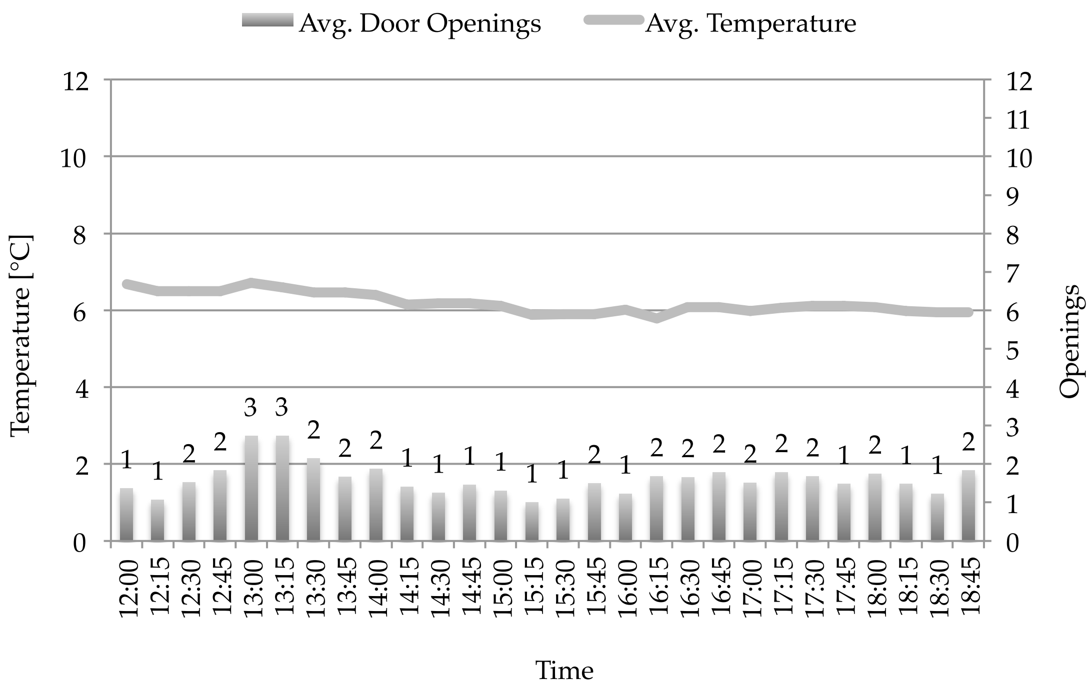


**Figure 86** **Workspace's average temperature and door openings per 15 minute periods during the AFTERNOON.**

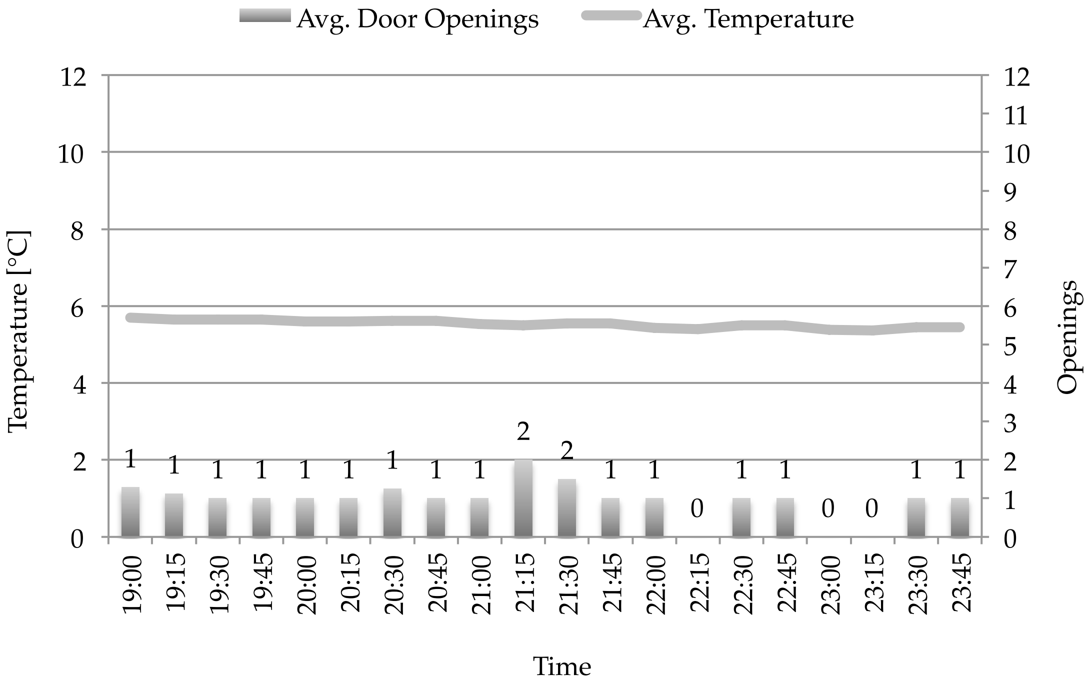


**Figure 87** **Workspace's average temperature and door openings per 15 minute periods during the EVENING.**

The batteries' autonomy was also to be tested. Using a multimeter, the voltage across the terminals of the batteries powering the EGGY Board of an active EGGY (of the household with ID #9) was measured on the 15th of March of 2016, 131 days after being deployed at the household's refrigerator.

**Table 41** **Average behaviour patterns towards the refrigerator usage of the household with ID #9.**

| Household's ID # ➔ | 9 |
|---|---|
| **Nr. Openings /day** | 22x |
| **Opening Duration** | 18s |
| **Δ Opening Duration** | ± 17s |
| **Temp** | 6.8°C |
| **Δ Temp** | ± 1.1°C |

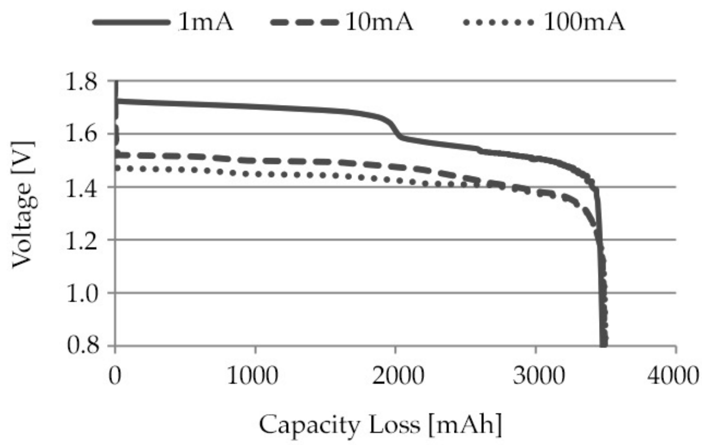


**Figure 88** **Constant current discharge profile of the batteries used as the EGGY power supply (Energizer L91).**

**Table 42** **Batteries' voltage status of the EGGY deployed at the household with ID #9, after 131 days.**

| | Voltage reading within 30 seconds after being taken from the refrigerator (approx. 7°C) | Voltage reading after 5 minutes exposed to the ambient temperature (approx. 23°C) |
|---|---|---|
| **Battery 1** | 1.66V ± 0.01V | 1.62V ± 0.01V |
| **Battery 2** | 1.66V ± 0.01V | 1.62V ± 0.01V |
| **Combined Batteries** | 3.33V ± 0.01V | 3.25V ± 0.01V |

Considering a daily average current consumption between 1mA and 10mA and linear losses, these curves indicate that a battery's capacity loss during this period of the tested device's deployment is between 1000 and 2000mAh, roughly one third and two thirds of their initial total capacity, respectively. Due to the use of a single device for this test, and the lack of accuracy provided by the method used, this result is not considered as conclusive.

Regarding game design related data, the average EGGnergy boost level per day, calculated using the data from the totality of households involved in this pilot, is 60%. The average deviation from this value within a day is 42%. The average number of points gathered per day by user is 6 727,64. Table 43 shows the overall ranking by March 15th.

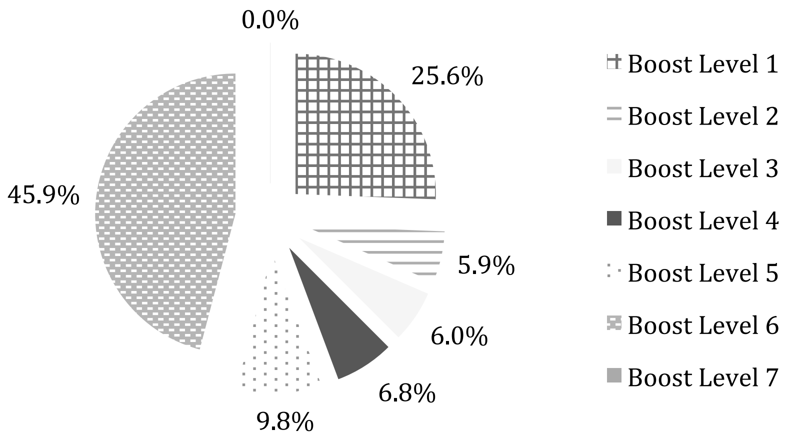


**Figure 89** Shares of the average time spent at each of the boost levels per day, considering the data from all the household of this pilot test.

It should be noted that not all of the households had their EGGYs at the same time, a fact that biases the overall ranking. Due to this fact further data is presented about each of the households EGGY deployment date, upon which it is calculated the number of days under this pilot, determined the number of points gathered on average per day, per household, and extrapolated a new ranking based on the number of points collected is all the households would have their EGGY running for the same amount of days – Symbolically 74 days, corresponding to the period between the 1st of January to the 15th of March of 2016.

**Table 43** Ranking at the EGGY Yolk by March 15th.

| Ranking Position | Household's ID # | Current Level | Total Number of Points Gathered [pts] |
|---|---|---|---|
| #1 | **9** | 20 | 1 056 570,10 |
| #2 | **6** | 20 | 797 886,10 |
| #3 | **7** | 19 | 645 609,70 |
| #4 | **12*** | 19 | 589 881,80 |
| #5 | **4** | 19 | 577 289,80 |
| #6 | **10** | 19 | 552 844,30 |
| #7 | **5** | 18 | 472 257,70 |
| #8 | **3** | 18 | 364 594,10 |
| #9 | **11** | 17 | 224 747,80 |

…

| Ranking Position | Household's ID # | Current Level | Total Number of Points Gathered [pts] |
|---|---|---|---|
| | | … | |
| **#10** | **2** | 16 | 204 000,70 |
| **#11** | **8** | 16 | 191 156,50 |
| **#12** | **1** | 14 | 83 906,30 |

Table 44 presents the updated, balanced ranking.

**Table 44** **Ranking updated as if all households would have had their EGGY deployed on January 1st of 2016.**

| Updated Ranking Position | Household's ID # | Deployment Date | Number of Days Active | Average Points Gathered per Day [pts] | Total Number of Points Gathered [pts] | Ranking Position Change |
|---|---|---|---|---|---|---|
| **#1** | **6** | 09/12/2015 | 97 | 8 225,63 | 608 696,62 | + 1 |
| **#2** | **9** | 05/11/2015 | 131 | 8 065,42 | 596 841,08 | - 1 |
| **#3** | **5** | 14/01/2016 | 61 | 7 741,93 | 571 902,82 | + 4 |
| **#4** | **7** | 20/12/2015 | 86 | 7 507,10 | 555 525,40 | - 1 |
| **#5** | **10** | 01/01/2016 | 74 | 7 470,87 | 552 844,38 | + 1 |
| **#6** | **1** | 03/03/2016 | 12 | 6 992,19 | 517 422,06 | + 6 |
| **#7** | **11** | 10/02/2016 | 34 | 6 610,23 | 489 157,02 | + 2 |
| **#8** | **4** | 11/12/2015 | 95 | 6 076,74 | 449 678,76 | - 3 |
| **#9** | **3** | 11/01/2016 | 64 | 5 702,41 | 421 978,34 | - 1 |
| **#10** | **2** | 08/02/2016 | 36 | 5 666,69 | 419 335,06 | = |
| **#11** | **12*** | 26/11/2015 | 110 | 5 362,56 | 396 829,44 | - 7 |
| **#12** | **8** | 08/02/2016 | 36 | 5 309,90 | 392 932,60 | - 1 |

To understand if there is a correlation between this updated classification and the average behaviour of each of the households this data is put side-by-side on Table 45.

**Table 45** **Ranking updated together with average behaviour of each household.**

| Updated Ranking Position | Household's ID # | Nr. Openings /day | Opening Duration | Δ Opening Duration | Temp | Δ Temp |
|---|---|---|---|---|---|---|
| **#1** | **6** | 27x | 16s | ± 12s | 6.5°C | ± 0.4°C |
| **#2** | **9** | 22x | 18s | ± 17s | 6.8°C | ± 1.1°C |
| **#3** | **5** | 6x | 32s | ± 54s | 6.1°C | ± 0.5°C |
| **#4** | **7** | 18x | 50s | ± 42s | 9.2°C | ± 0.9°C |
| **#5** | **10** | 9x | 21s | ± 37s | 6.4°C | ± 0.6°C |
| **#6** | **1** | 18x | 16s | ± 12s | 6.9°C | ± 0.8°C |
| **#7** | **11** | 10x | 52s | ± 1m 23s | 9.3°C | ± 1.0°C |
| **#8** | **4** | 10x | 31s | ± 61s | 5.4°C | ± 1.1°C |
| **#9** | **3** | 18x | 1h 2m 17s | ± 12m 59s | 7.5°C | ± 1.0°C |
| **#10** | **2** | 8x | 15m 19s | ± 29m 1s | 6.4°C | ± 2.1°C |
| **#11** | **12*** | 40x | 24s | ± 15s | 6.5°C | ± 0.8°C |
| **#12** | **8** | 13x | 49s | ± 1m 33s | 8.5°C | ± 0.3°C |

Regarding the EGGY Yolk's engagement, on average the users spent 3 minutes and 44 seconds consulting the app, per visit. No data regarding the specific navigation flow within this time was obtained.

6

# Conclusions

## 6.1 Conclusions

The conclusions of this work would consider three categories – Regarding the fundamentals, the implementation and the preliminary results harvested.

### 6.1.1 Fundamentals

The fundamentals of this work enclosed three main topics – The domestic energy efficiency present scenario, Energy Management systems and the Internet of Things, divided by the literature review and the state-of-the-art chapters of this document. Follows a compilation of conclusions in the form of a list regarding these subjects, founded on the information provided by the documentation listed at the bibliography chapter of this document.

**Domestic Energy Efficiency**

– Danish national statistics lead to suggest that electricity consumption for lighting and appliances is more dependent on user practices than on the appliances' energy efficiency, specially if the number of appliances is counted as part of the user practice [16];

– Part of the efficiency brought by the installation of efficient appliances or the building's improvement (approximately 20% for heating-based solutions [20]) is lost to the rebound effect, which states that taking control away from the customer cannot be relied upon to improve the situation, as it may actually entrench and legitimize high-demand practices, disengaging customers from any need to consider and question the appliances usage or any other effort towards energy consumption control [47].

- Regarding interventions that impact on behaviour change towards domestic energy efficiency, a study which considered commitment, goal setting, information, and modelling as a-priori interventions, while several levels of feedback and rewards as a-posteriori interventions concludes that goal setting is more effective when combined with feedback, that a personalized approach such as tailoring may turn to be more effective and that modelling – which entails the provisioning of recommended behaviours – was acknowledged as impactful in knowledge increase and was also considered to be effective in reducing the energy use. When concerning a-posteriori interventions this study also concludes that the more frequent a feedback is given the more effective it is. It is also stated that combining comparative feedback with rewards in a contest setting proved to be successful, but that several studies point to the fact that this is, by itself, rather short-lived [21].

- A Portuguese study concludes that it is possible to automatically and anonymity extract and group persistent routine patterns in households, and that this information is useful to help design better incentives for load shaping and the development of new services, tailored to specific populations [23].

- A research conducted in the USA suggests that in-home devices and displays providing real-time feedback may generate electricity savings of 5% to 15%, on average, and that customized, regular feedback handled to customers may motivate residents to lower energy use from 0% to 10% [26].

- Darby et al. concluded that the theory of *affordances* points to the fact that much of the significance of socio-technical innovation, as it is the smart metering, can be described in relational terms – in terms of how people and things interact with other people and things, and to what ends. And that it should involve a great deal more than automation and fine control [25].

- Regarding modern refrigerators' energy consumption and usage impact, Alissi et al. concluded that room temperature has the higher effect on energy consumption (two tests resulted on average energy consumption rises of 47Wh and 53Wh for every increase of 1°C on the room temperature), followed by door opening (9Wh and 12.4Wh per door opening with 12 seconds of duration) and thermostat setting position (energy consumption increase of 7.8% for each level reduction) [35].

**Energy Management Systems**

- A study states that Energy Management (EM) systems must provide advanced and versatile functionality while keeping the installation simple and running cost low, and that they should integrate with users' daily activities and offer actionable feedback. Also according to this study, EM systems can serve as a useful tool towards active *demand side energy management*, one of the fundamental goals of a smart grid – to influence the consumers' energy use behaviour, to either turn on/off or reschedule the use of their appliances. It is further emphasized that EM systems should also provide a framework for goal setting and allow consumers to track their progress toward their self-specified goals related to behaviour change, as a way to successfully incite the consumers to improve their behaviour continuously and under a long-term [49].

**Internet of Things**

- 39% of the world population is connected to the Internet (as in 2014). Almost 6 hours are spent a day, on average by adult user on the USA, consulting online digital media. 51% of this time on a mobile setting. It is predicted that 50 to 100 billion things will be electronically connected by the year 2020 [42].

- "On the way towards 'Platforms for Connected Smart Objects' the biggest challenge will be to overcome the fragmentation of vertically-oriented closed systems and architectures and application areas towards open systems and integrated environments and platforms, which support multiple applications of social value by bringing contextual knowledge of the surrounding world and events into complex business/social processes". The reasons for this heterogeneity include energy limitation, reliability required from the wireless medium, security and privacy concerns, monetary cost of the node devices, radial distance between two nodes, spectrum noise, limit size of the node devices, available infrastructure, private technology, among others [42].

- The middleware can be defined as the software layer that binds the physical layer (e.g the hardware) with the application one, and it is responsible for providing the abstraction required from the heterogeneity and complexity of the underlying technologies of the physical layer. As so, the middleware is the major contributor to the IoT's interoperability today [43].

### 6.1.2 Implementation

The conclusions taken about the implementation are divided between software and hardware related categories.

**Software**

- To prevent future constraints to integration and interoperability all the architecture of an IoT solution should be careful thought to use the most adaptive tools available for processing and storing data. It should also detach as much as possible the software layer from the hardware layer, by developing dumb-things supported by smart, centralized cloud-based software – leaving just very simple action-reaction pair behaviour to the device, focused on harvesting, shipping, and setting its actuators upon data – instead of smart-things.

- The protocol developed to orchestrate the communication between the device and its Agent, named EGGTTP, proved to be effective. Both entities proved to be able to keep synchronized without any loss of data, while minimizing the overall connection time and consequently maximizing the lifespan of the device's finite power supply.

- The Agent – A piece of processing of a remote server dedicated to a specific IoT device – showed to be a valuable first layer of remote intelligence that grants a better performance and reliability for regular tasks that are frequently required by a device, when compared to a centralized processing unit which would lose the ability to have volatile data constantly available about a given device.

- The Agent ran all its functions and procedures developed successfully. No errors or bugs were detected in these processes.

- The Non-SQL database used already proved to be a valuable asset for quickly growing Web Platforms in general but in particularly those that are fed by very heterogeneous environments as the IoT. The introduction of Data Frames, a first level of pre-processed data, stored at the Database, contributed considerably to a crucially good performance on the access to the information required by the User App.

- The MVC architecture used by the Web App allowed the creation of objects to represent main blocks of this IoT scenario, as User and EGGY, and contributed to the development of the interoperability of the platform.

- No errors or bugs were detected on the code associated to the Web App.

- The User App presented the friendly layout and user communication that was intended. The addition of features to bring an increase of motion to the interface was considered as an important development for guaranteeing a better engagement of the App. The enlargement of the number of game-related elements was also set as an important milestone to achieve this goal.

- Future features to improve the interaction between users at a virtual level through the use of the User App are required to improve the engagement of the users with their behaviour improvement.

- Some minor problems that do not impact on the users' ability to use the application were detected on the interface, depending on the version of the web browser being used to access it (between Android 4.4+, iOS 8.4+, and Google Chrome for Desktop).

**Hardware**

- The switching off and on of the device isn't always successful if the device is currently at a sleeping state. The presence of a high capacity capacitor, placed between the switch that controls the EGGY Board's power supply and the board itself, is impacting with the restart of the device, which is often a use case while attempting to configure the device for a first time. As the switch is turned-off, this capacitor turns into a power supply while it discharges its accumulated energy. If the device gets into a sleeping period after an unsuccessful configuration process, as a way to guarantee that the user does not forget the device at a high power consumption state, only a hard reboot (the cut-off of the energy supply) would be able to trigger its awakening. As the board is still fed by the depicted capacitor for a considerable amount of time (typically several minutes), it would be necessary to wait for the full discharge of this capacitor for a restart to be successful. A solution to this problem is presented further ahead in this document as future work.

– The device may reboot unexpectedly due to firmware updates set by the Electric Imp server. As it does so, the LEDs that are intended to give feedback to the user about the device's connectivity may light up. This is causing for the device to interpret this light as a door opening, which contributed to pollute the results of the preliminary pilot. Further information about the impact of this problem is discussed at the preliminary results section of this chapter, while a solution is presented as future work.

– It was defined as important to guarantee the rechargeability of the power supply. Further tests over the battery usage of the deployed devices are required. It is necessary to enlarge the number of devices tested, as the current only considered one device (which was put into high-stress conditions), and also to improve the accuracy of the method used, which resulted in a very broad conclusion – one third to two thirds of the batteries' capacity were used by the tested device in 3 months and 11 days. This points to 7 to 9 months of autonomy, considerably below the 24 months determined theoretically. This may be justified by the fact that the device's operation has not been completely stable over this period.

– Excluding the above problems presented, the device proved to complete the tasks that it was expected to perform in a solid manner. It showed to be fast on reacting to door openings and accurate on reacting to temperature changes.

– The price to produce this technology (close to 15€, lowerable with scale) is considered as a value that improves its massification prospects, regarding the state-of-the-art analysed. This value may further lead to the technology's adoption by local utility companies and its offering at subsidized prices to their customers feasible, as utilities are motivated to meet their sustainability and energy efficiency goals, and making their operations more reliable and cost effective, as depicted by Saima et al [49].

- The device developed is considered as easy to install, to which it contributes the BlinkUp technology used for its configuration and also the fact that no attaching to an appliance is required, as the EGGY device is simply to be put inside a refrigerator. The latter also impacts on the retrofitting of this technology to older refrigerators and consequently on the device's prospective user base.

### 6.1.3 Preliminary Results

The sample of data used for these tests is not considered to be relevant enough for the results to be conclusive. It is also clear that the issues identified with the hardware, namely the occasional occurrence of "door openings" caused by the device's own LED flashing, further referred to as the *spurious door openings problem*, polluted these results. However, this test had the main goal of testing, validating and design corrections on a validation template for further testing, as a larger sample is available, a task which is considered to be successful. The results gathered are further discussed in the form of a list, separated by Level.

**Level 1**

- The average number of door openings seems to have a correlation with the number of people of a household, as it would have been predicted by the common sense. The information presented determines that this correlation between the two variables is non-linear, as it presents a big gap between households with 2 or fewer members and those with 3 or more. The maximum number of door openings showed a similar pattern. The results for the minimum number of openings are less diffuse, and do not clearly state that these rise with the households' size.
- The results regarding door openings' duration are considered to be very polluted with spurious readings that are consequence of the "door open-

ings" caused by the device's own LED flashing. However, it should be noted that this data does not clearly state the existence of a correlation between the households' size and the average time opened per door opening.

- The average temperature results show a non-linear correlation with the household's size, rising monotonously from 6.1°C to 9.2°C. The maximum and minimum values do not state the existence of a correlation.
- Among the group of households with two members, three of the four members have their average number of door openings differing by one door opening, while the forth showed a very dissimilar value. This household with the largest average number of door openings also showed the highest average temperature.

**Level 2**

- The group composed by households with children showed the highest value of average door openings per day (18x), followed by the households with retired or unemployed members on their composition (13x) and finally those with solely employed adults (10x).
- The families with solely employed adults left the door opened for longer on average (51s), followed by those with retired or unemployed members (48s) and finally the families with children (16s).
- The average temperature was the highest for the households with retired or unemployed members, followed by those with children and finally the households with solely employed adults.
- No bind was verified between the highest number of door openings and the highest temperature on this data set.

**Level 3**

- The households that when inquired answered to have active occupancy for more than 6 hours per day (13x), on average, opened the refrigerator door more times, on average, than those that answered to spend less than 6 hours (10x). However, considering the data of the other levels of analysis and the differences observed, this difference does not seem to be relevant.
- The highest average temperature was registered for the group of highest refrigerator usage indicators.

**Level 4**

- On average, the group composed by all the households evidenced an average number of door openings per day of 18.
- On average, the households left the door opened for 16s, per opening. The standard deviation observed for this value was 12s.
- The average temperature observed within the households was 6.9°C. The standard deviation observed for this value was 0.8°C.
- The average hourly data for the temperature demonstrated to be very noisy, leading to inconclusiveness. Regarding the hourly average number of door openings, the fact that, on average, at least one door opening was verified for all the quarters of hour, even on late hours, leads to deduce a problem on this calculation or an over-pollution of the spurious door openings problem already depicted.
- The workspace's data showed a considerably more intense usage of the refrigerator, with an average of 40 openings per day.
- The hourly data for the workspace showed to be considerably more reliable than that of the households. The temperature variation was smoother, and the presence of quarters of hour with an average of zero openings during periods of no occupancy were observed. However, it is still visible the effects of the spurious door openings problem on these results.

**The Curious Case of the Poached EGGY**

- One particular EGGY, baptized by its owner as Escalfado ("Poached" in the Portuguese language), belonging to the household with the ID #3, posed a particularly interesting case. As seen by this household's average data, showed on Table 46, very long openings were being registered for a long time, apparently periodically. As the owner was already tracking its refrigerator's consumption it decided to cross this information with the large openings' cycle reported by the EGGY. With it, the owner understood that the EGGY would only consider the door to be closed (absence of light) when the refrigerator's compressor was working. By introducing a camera inside the refrigerator to track light variations, the user learned that a problem in the refrigerator's electric circuit was causing the refrigerator's internal light to be turned on while the compressor was not working, thus explaining the EGGY's accurate reports.

Table 46 **Average behaviour patterns towards the refrigerator usage of the household with ID #3.**

| **Household's ID # ➔** | **3** |
|---|---|
| **Nr. Openings /day** | 18x |
| **Opening Duration** | 1h 2m 17s |
| **Δ Opening Duration** | ± 12m 59s |
| **Temp** | 7.5°C |
| **Δ Temp** | ± 1.0°C |

**Game Related**

- Table 45 indicates a poor relationship between a good behaviour (less door openings per day and for a shorter duration) with an overall ranking position. Further results should be tracked to determine the source of the problem, namely if the algorithm for points attribution is not in fact fair, or if this result is explained by any error on the attribution of points.
- A problem in the software did no allow any user to reach a maximum boost level of 7. Even so, the percentage of time spent on average by the EGGYs at the highest boost levels (45.9% at the boost level 6) indicates that the game is not being demanding enough in terms of boost level scaling. This should be revised in a future version of the game architecture.

## 6.2 Future Work

The future work, to follow the one presented in this document, would consider two categories – Regarding the implementation and the consequent validation required.

### 6.2.1 Implementation

The following describes the next steps suggested towards improving the solution to be more effective on promoting the energy efficiency of households and the interaction with the energy systems.

**Software**

- The game set at the EGGY Yolk should be provided with features that promote the interaction between users, the competition and cooperation between them to improve each other energy efficiency related behaviours. The next topics present suggestions to achieve this goal.

- It is suggested the inclusion of Challenges. A Challenge should be defined by four attributes – A Target, a Period, a Context and a Goal. The Target should define who is involved in the Challenge, it may be self put (e.g. the own user is the Target) or another entity, as another user or community, can be set as the Target. The Period should define the duration of the Challenge, after which the results of the Challenge are determined. Several levels for the Period should be available, as daily, weekly and monthly. Context defines the variable that is being evaluated in a given Challenge, as Door Openings, Time Opened or Temperature for behavioural metrics, or Points, Level or EGGoins for game related metrics, for example. Finally, the Goal defines which is the condition of the Context to be evaluated by the end of the Period. It could be set to be Larger Than, Smaller Than, Equal To a specific value or one relative to results of a Target. Some Challenges may be set as recursive by the platform.

- The granting of EGGoins should be designed and implemented. EGGoins should be won by completing specific achievements, as the ones set by the previously presented Challenges. The EGGoins should then be used at a Store set at the EGGY Yolk.

- The EGGY Yolk Store should be design to allow an easy management of the offers by third party retail partners. Besides this offers, the Store should also be provided with virtual artefacts (as Powerups) to be used within the game setting. The user should be presented with the strategic option to use its EGGoins on offers or to use them into these artefacts that it may use to get advantage in the game, to have a payback with an increased number of EGGoins. This is considered to enlarge the number of gaming knots and consequently improve the engagement of the game.

- The EGGY Yolk's backend and layout should be reviewed to allow the association of several EGGYs to a single user.

- The EGGY Yolk's backend and layout should also be reviewed to allow the association of several users to a single Family entity.

- The EGGY Yolk's backend and layout should be make ready to allow other Nests rather than a Fridge.

**Hardware**

- The Awakening Problem depicted in the Conclusions of this work should be corrected. This is to be achieved by taking the capacitor that is causing the problem from its current position and introduce it between the power supply and the switch, so that it won't feed the circuit while the switch is cutting-off the power supply.

- The other problem identified by the Conclusions of this work, regarding the device's mistaking of its own LED lighting with a door opening should be corrected. This can be achieved by allowing the device to disable its LED blinking, something that by the time is automatically controlled by the Electric Imp's microcontroller. The manufacturer does not allow the control of this LED lighting by software, which means that additional hardware should be added to allow one of the I/O pins available to be used as an enabler or disabler of the LED's power supply. This additional hardware logic should also have memory features, as it should be guaranteed that the last binary value imposed by the control pin is maintained.

- A new EGGY Board prepared to hold a larger, generic set of sensors for inferring about a larger number of domestic energy efficiency impacting behaviours should be designed and prototyped. This board should be ready to hold a movement sensor, a humidity sensor, a CO2 sensor and a microphone, besides the already available light and temperature sensors.

- In order to avoid the use of the proprietary BlinkUp technology and also to bring a feel of augmented reality to the device, it is recommended the development of a technology which is here baptized as BeepUp. The device is to be able to listen and process the kind of 8-bit melodies that it already uses for giving real-time feedback to the user, as a form of language. The user would then be able to communicate with the device by setting a sequence of 8-bit beeps, played by any electronic device, as a smartphone, analogously to what is done with the LED flashing by the BlinkUp technology.

- The device should be provided with a rechargeable power supply. The power supply circuit would have to be revised. The rechargeability should be provided by a micro-USB port at the bottom of the EGGY Shell.

### 6.2.2 Validation

- This study's Pilot Project and Conclusions Chapters aimed to present a base template for a more meaningful research, with a larger set of users involved in a pilot test. It is suggested that study with 100 households involved is conducted to achieve the validation proposed by the objectives presented at the Pilot Project Chapter of this document.

- It should be further validated that the data analysis provided by the developed EGGY Yolk's Control Panel is accurate, and new features for controlling the results in real-time should be provided in order to quickly tackle hypothetical incongruences that may be discovered.

- It should be tested if data regarding the refrigerator usage can be used to infer about the respective household's occupancy over time (binary presence and number of occupants), as this information is particularly relevant for energy utilities to use for predicting energy use. To perform this research, it is suggested that the occupancy of a set of the households of the EGGY pilot is registered, by asking the household's to register their entrances and exits of the house manually, or by distributing a simple device, provided of two buttons for registering an entrances and exits, respectively, connected to the EGGY Yolk Database. After the harvesting of this data, it is recommended to cross it with the EGGY data and to train a neural network with the combined results. The resulting algorithm should later be tested with another household, and its output should be confronted with the household's registered occupancy. The level of accuracy of this algorithm should finally be determined.

- Further validation about the EGGY Yolk usage and internal navigation should be determined by the use of Google Analytics' toolbox.

# 7

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*To be continued!*