International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:14, No:12, 2020

Reduction of Energy Consumption Using Smart Home Techniques in the Household Sector

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Abstract**—**Outcomes of exhaustion of natural resources started influencing each spirit on this planet. Energy is an essential factor in this aspect. To restore the circumstance to the appropriate track, all attempts must focus on two fundamental branches: producing electricity from clean and renewable reserves and decreasing the overall unnecessary consumption of energy. The focal point of this paper will be on lessening the power consumption in the household's segment. This paper is an attempt to give a clear understanding of a framework called Reduction of Energy Consumption in Household Sector (RECHS) and how it should help householders to reduce their power consumption by substituting their household appliances, turning-off the appliances when stand-by modus is detected, and scheduling their appliances operation periods. Technically, the framework depends on utilizing Z-Wave compatible plug-ins which will be connected to the usual house devices to gauge and control them remotely and semi-automatically. The suggested framework underpins numerous quality characteristics, for example, integrability, scalability, security and adaptability.

Keywords**—**Smart energy management systems, internet of things, wireless mesh networks, microservices, cloud computing, big data.

I. Introduction

ENERGY is a crucial component of every human's life. This has been begun from the endeavors of people to get heat by burning firewood in primitive stoves, wound up with constructing technologically sophisticated nuclear power stations to produce power and kinetic energy. Sadly, the humans' needs to generate more power ended up having a negative impact on the whole ecosystem, which can be observed by the continuously shrinking forest territories, atomic catastrophes, greenhouse-effect and weather changes. Moreover, the world's population fast-growing and the expanding of high living-standards expectations led to boosting the pressure for yet more energy dramatically. This brought huge challenges to our modern society to maintain a healthful and balanced relationship to our restricted-resources plant. Mitigating these challenges can be accomplished by on one hand focusing endeavors on producing clean energy from renewable resources, and on the other hand, decreasing the consumed energy by using the available energy adequately and efficiently. In the last few decades, researchers have introduced several appropriate and pragmatic methods to generate clean and affordable power from regenerative resources. This can be seen in the rapidly increasing quantity of wind energy converters in many countries. In Germany, according to [1], the number of such plants has grown by 227% between 2008 and 2016. However, these efforts still miss the optimal ripeness to deliver a complete response to the urging energy demand. On the other hand, many endeavors have been made to construct energy-saver devices and machinery that keep delivering the same level of service while consuming less energy.

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The suggested RECHS framework is an attempt to support this approach by offering management of household devices to reduce energy consumption and managing energy providers to reduce energy bills. Everything begins with constantly measuring of energy consumption of the appliances using Z-Wave based plug-ins manufactured by AEOTEC (AEON Labs). As time passes, the system will have enough energy consumption figures for every measured device, so it can suggest alternative devices from the market. The main focus will be on the devices with the highest energy consumption rates; the figure obtained from eurosats [2] shows that heating, ventilation and air conditioning (HVAC), and refrigeration are absorbing 40% of the total energy used in a household. Moreover, the suggested framework suggests another approach to detect the standby modus in an appliance, for instance, a TV, and shut down when it is not used based on predefined rules, such as the standby span time. It is important to distinguish between two frequently repeated terminologies in this area: Power and Energy. According to [3], both terms differ in the meaning; "The energy of any system is describing its capability of doing work, regardless of how long it takes to accomplish it. However, power is the time rate of expending the energy and doing the job". The relation can be represented via: $r = (Work\ (Energy))/Time = W/t$.

The main aim of the RECHS Framework is enabling household occupants to manage their appliances energy usage. This main target can be split down into following SMART based objectives: First – Collecting, storing energy consumption from at least three appliances, for at least three months, then converting these figures into charts and suggestions. After setting up the system by attaching the plug-ins to the chosen devices, the main Application Programming Interface (API) starts receiving the energy consumption data from plug-ins, where it gets saved in a relational database. In the background, routines run frequently and independently to analyze and create correspondent graphs on real-time. Second – Once the energy consumption is tracked for at least three months, the system should start showing suggestions to replace the measured appliances by newer ones with similar attributes and more efficient energy consumption. The Return on Investment (ROI) should be achieved within a specified period. This period cannot be fixed because it depends on the local market, prices and tax rates. The eBay portal will be used to retrieve suggestions about potential new devices and will provide offers to buy the old ones, which may be used by recycling companies or as spare parts, but definitely not to be put in service in another household as is. Third – Making recommendations to cut down 10% of the Carbon Dioxide (CO_2) emissions caused by the electricity generation from nongenerative sources. According to [4] reducing energy consumption will automatically lead to reduce the CO_2 emissions. The rate between every kWh and CO_2 (per kg) varies from country to another because of the dependence on the way how the energy generated in this particular country. For instance, this rate (kg CO_2 per kWh) is 0.013 in Sweden, 0.281 in the UK and 0.296 in the EU countries [5]. Fourth – Suggest -at least- two different local energy suppliers to replace the current energy supplier. This nice-to-have feature does not have a direct impact on electricity generation or consumption unless there are local energy suppliers who offer clean energy generated from renewable sources. This approach may affect the household budget, and increase the social acceptance to the framework by making it financially attractive. As a prerequisite, the administrator is required to provide the system with the name of the local energy supplier and/or the unit price. The system relies on external API providers who provide information about the offered electricity unit price. Fifth – An immediate reduction of the daily electricity consumption by -at least- 0.5%. This occurs shortly after start running the system using two different approaches: 1) Manually by switching-off appliances by setting up a pre-defined schedule. 2) Automatically, by detecting the standby modus, when is the energy consumption is very minimal, but not nil, every 5 minutes (for example), and shutting down the device completely. Important to mention that this feature cannot be applied to all appliances and must be configured by an administrator. Applying such feature in the refrigerator will cause severe harm to the stored food, however, a TV, which is left the whole night in standby-modus, is a good candidate for that.

II. Energy Management Approaches

The household sector is one of the largest sectors in the society where the energy demand is high. To reach better rates in the generated and consumed energy, and ultimately the amount of produced CO_2, efforts must be concentrated in this sector worldwide. In the literature there are mainly five different research aspects: First –all methods and efforts done in order to prevent the waste of using energy (passive methods), and reducing energy management (active methods). Second – a general overview of industrial attempts made to produce products that have low power consumption rates. Third – Extensive analysis of existing wireless communication protocols used in the home-automation segment, including Z-Wave, ZigBee, Insteon, Bluetooth and UPB. Finally – a collection of statistics and facts regarding energy consumption and how it affects our planet.

A. Passive Methods

Generally speaking, all efforts done to reduce the needed energy are considered “passive method”. This approach is mainly applied during constructing phases by choosing proper materials, appropriate building methods, adequate structures and fitting design. According to [5], up to 33% reduction percentages can be achieved when passive methods are properly implemented during the construction phase; i.e. “different construction methods including the design of the external walls, floor plans, used insulations techniques and materials”. Liang and Roskilly [5] have concluded that using cavity walls lead to reach higher rates of saving energy, than using the classical brick-solid walls. Moreover, much better isolation rates can be reached when applying the polyurethane instead of the air while constructing insulations. Figures show the same fact, cavity wall with air may lead to saving up to 7.9% of the energy, however, the combination of using cavity walls with polyurethane may bring saving up to 33.38% [6]. According to [7], some principles suggest that the insulation upgrade from approx. 8 cm to 30 cm may bring up to 20% of reduction of the heating bill, and up to 10% reduction of the cooling costs.

B. Active Methods

All activities aim to reduce energy consumption while keep offering the same comfort level are considered within the active methods pallet. One of the well-known examples is room lightning. The service “having light in the room” can be achieved by utilizing old-styled, high-energy requiring bulbs, or by using energy-saver, environment-friendly LEDs. In this case, the decision which product to use is the crucial impact on the energy consumption rates. In the literature, active methods are divided into three main groups: Measurements, household’s occupants’ behaviors, and utilizing advanced technology.

Measurements: Any enhancement and improvement efforts must begin with measuring the AS-IS situation [8]. Reducing energy consumption is not different, therefore, in the market, there are several methods and technologies are introduced to fulfill this job, such as documenting the monthly bills by using an inexpensive and easy-to-use plug-load product such as "P3 Kill A Watt EZ" [10]. The same approach has an advanced version known under the name "Kill A Watt Control". This advanced edition offers possibilities to quantify and turn devices on/off based on a pre-programmed schedule. This solution can be applied nearly in any environment, regardless if it is smart or not. However, implementing it in a smart-home-environment together with other ZigBee protocol-based smart plugins such as "Digi XBee Smart Meter" and "Belkin WeMo Insight Switch" makes it possible to use its innovative features. "Ted Energy Detective Pro Kit", "Neurio's Home Electricity Monitor", "Blue Line Innovations PowerCost Monitor" and “Blue Line Innovations PowerCost Monitor” shown in Fig. 1 are examples of off-the-shelf, complete solutions which are capable of measuring the energy consumption, and controlling the attached appliance remotely by enabling the switch ON/OFF function.

Fig. 1 Blue Line Innovations PowerCost Monitor [9]

Household Occupants Behaviors: Household occupants play an essential role when it comes to actively reduce energy consumption. This can be summarized in many fields: First – The energy consumption can be reduced significantly when household occupants pay more attention to switch-off any unused electrical item, such as bulbs, Heating, Ventilation, and Air Conditioning (HVAC) devices. Second – Appropriate sizes of various household appliances must be chosen to match the number of occupants who live in the household. This approach will have a direct impact on the consumed energy. For example, purchasing a four-slices toaster, or a big-size microwave for a family of two is considered a sort of exaggeration, similar to using a sledgehammer to crack a nut. Third – An appropriate and frequent cleanup and maintenance keeps various devices in shape and maximize their service; for instance, furnace, vacuum cleaners, etc. Fourth – The precise adjustment and setting the thermostats according to the needs leads to saving energy in huge amounts. Fifth – In case the household is equipped with HVAC, covering radiators is a failure behavior which must be avoided. Sixth – Curtains must be closed at night to act as isolation layer and keep the house warm. Seventh – Household occupants are required to prepare their appliances before leaving for a long-time absence, for instance going on a vacation. This includes shutting-off all appliances that consume energy while being in a standby-mode such as TV, printer, computers. Eighth – Certain types of appliances such as washing machine, dishwasher and dryer, must be turned on only when they are fully loaded . Although most modern appliances are equipped with sensors to measure the fullness of the device, and to adjust the running times and intensity accordingly, household occupants must make sure to run appliances on full load. This rule applies for some appliances such as washing machine, dishwasher, and dryer.

Brandon and Lewis [11] have analysed the energy consumption behaviours in 120 households, for nine months, in Bath in the UK. This study has revealed that the following hypothesized key factors influence the energy consumption in the household segment: 1) Income constraints – that includes household income and historic consumption. The increase in income leads to an increase in energy consumption. 2) The behavioural and structural potential for change – Increasing the environmental awareness of householders is extremely affected by the willingness of change, which is related to the educational status, cultural background. 3) Environmental attitude – People with ecological awareness show more respect to the resources in general and more likely to reduce their energy consumption, comparing to others with less environmental awareness. 4) The characteristics of the population such as age, gender, ethnicity, education level, income, type of client, years of experience, location, etc.

Applying Advanced Technology: With the industry evolving nearly in every field, home-automation is also gaining huge steps towards having sophisticated technological improvements. So taking advantage of these technological advancements may bring a lot of advantages towards reducing energy consumption while maintaining the same level of comfort. Examples of such products in the market are: 1) Nest from Google. 2) Lux Geo Wi-Fi Thermostat. 3) Honeywell Home Lyric and Wi-Fi 7-Day Programmable Thermostat.

Due to many reasons, including environment, monetary and policy-driven issues, in the most recent decades, the high focus was put on issues related to the energy generation and consumption. Endeavors were invested to acquire clean energy and diminish the consumption either by creating new, high-efficient devices or lessen the running time of those apparatuses or both. Famous manufacturers attempt to produce many new products in the home automation field, however, these products still did not reach the desired ripe grade, either because it offers special solutions for special fields, or it offers closed applications without following industry-wide standards. The following section is there to explain the RECHS Framework and demonstrate the justifications and show its strength and applicabilities. It shows the potential how such a framework may be considered as a seed for further development and future work.

III. The RECHS Framework

As we've seen, all previously mentioned approaches either offer precise solutions and answers for local issues or are built on specifically manufactured technology and standards by solo vendors. Moreover, part of these solutions present measurements; others offer control-units either directly or pre-scheduled. Nevertheless, none of them offers any hardware-independent units. These solutions do not offer all components in one place, listed in one package, without being restricted by certain hardware or protocol.

Following is a brief of most points describe how RECHS Framework (Fig. 2) differs: First – It is hardware-independent. This means that any type of hardware equipped with any home-automation protocol compatible devices can be used and implemented without any need to perform pervasive modifications to the application, in other words, new hardware nodes can be simply attached as a "plug-and-play" node. Second – All relevant modules are offered in one place, these are: A) Electricity Consumption Tracker & Recorder (ECTR): is responsible for tracking and storing the energy data including Amps, kWh and Watt, which are collected from plugins attached to appliances. B) Appliances Replacement Recommender (ARR): uses the appliances' metadata entered by the system administrator and uses the energy consumption rates of this appliance to perform search actions in the online-portal eBay to find similar products with better energy efficiency attributes and suggests the householder buying these appliances and sell old ones to reduce energy consumption. C) Standby Detector & Optimizer (SDO): is responsible for tracking and indicating the standby status of appliances and cut-off the energy entirely after the standby-limit is exceeded. Not all appliances are a proper candidate for this module, therefore a pre-configuration is necessary. D) Energy Provider Optimizer (EPO): is a basic module responsible for comparing attributes, prices and services of local energy suppliers with the currently used one and recommend swapping it when improved conditions are discovered. Replacing energy supplier may be also recommended even the new one offers the same price level, or even when it has slightly higher rates, this occurred in case the new supplier offers energy generated from clean and regenerative sources. Third – It is protocol-independent. RECHS Framework is not bound to a particular protocol. All protocols that support home-automation such as ZigBee, Insteon, Bluetooth, KNX-RF and UPB, can be used. The major criterion is the fact that energy consumption can be collected and some basic functions such as switching ON/OFF are supported. Replacing the protocol may require implementing related connectors. Fourth – It is flexible. RECHS is not also bound to particular hardware or plugins or nodes. In the following case study, Z-Wave based hardware called AEOTEC manufactured by AEON LABS is used. This can be easily replaced with any other Z-Wave based hardware, without the need to make any change, and also can be substituted by any other home automation protocol based hardware, but then a new connector may be needed. Fifth – The RECHS framework comes up with a GUI and connectors, all these are published in public repository domain in GitHub with free-of-charge access and modification right. No developer license is needed. No developer license is needed to further develop it.

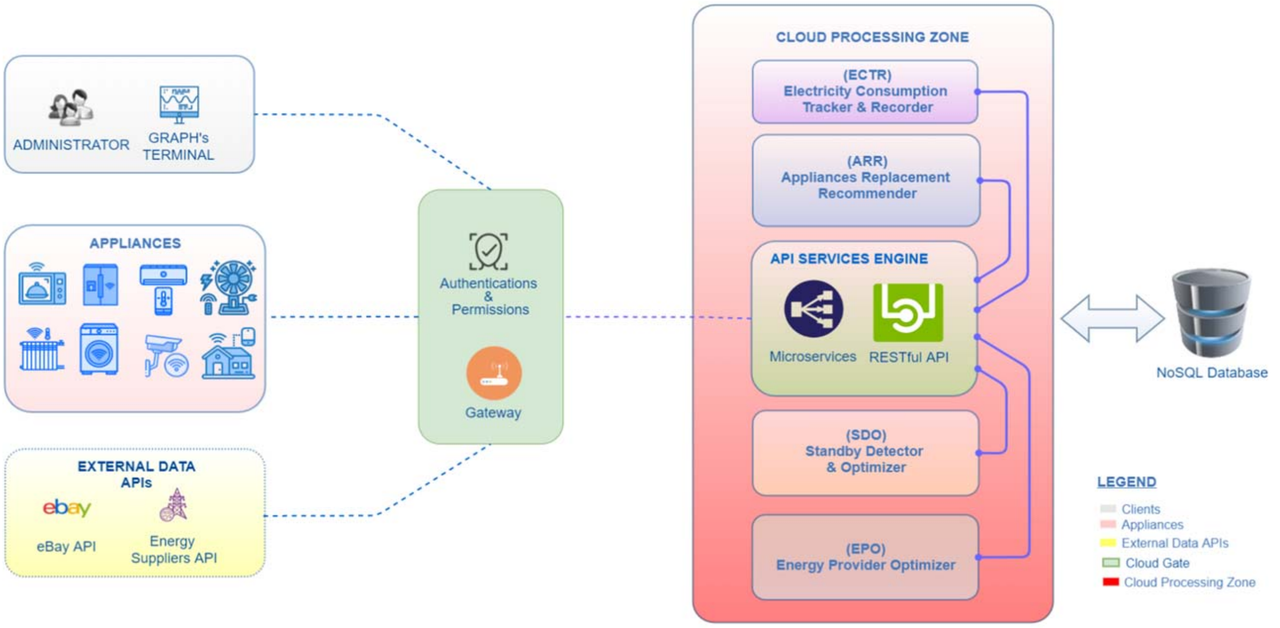

Fig. 2 RECHS Framework Overview

IV. Experiment

Applying this framework on a household will be done using the waterfall project management methodology. Therefore planning, documentation and creating a prototype should be done during the initial phase of the case study. This section describes the related SLC phases including planning, analysis, design, implementation, testing and maintenance. The unit where the framework is applied is a 130 m^2 flat, located within an Oceanic climate zone. It has four occupants, equipped with usual household's appliances including a gas-based underfloor heating system and no air conditioning unit. For this case study, three appliances will be used: 1) TV, 2) Refrigerator and 3) A 100-watt ordinary light bulb.

A. Design

The application's overall architecture is illustrated in Fig. 3. As seen in the architecture, besides the RECHS's core system, some additional external modules and APIs such as; eBay Product Search API, Energy Providers Portal API are added to feed the system with further necessary services.

As mentioned before, the waterfall methodology will be applied. One of the SLC phases is the design phase. This phase has been achieved by creating 1) Different use-cases, including managing users/households, tracking and recording energy consumption data (Fig. 4), managing profile, managing nodes/appliances, managing scheduled tasks, replacing the current appliance with more efficient ones, replace energy provider, activating the SDO. 2) A class model. 3) Sequence diagrams to track and store energy consumption data, also to manage users, profiles, nodes. Moreover, some diagrams were built to offer search-and-replace appliances and energy suppliers. Finally, a sequence diagram is created, illustrated in Fig. 5 to design activating the standby modus detector and optimizer. 4) Activity diagrams also to design the same modules to manage different components, and offer a replacement of appliances (Fig. 6) and energy providers, and finally handling the standby modus.

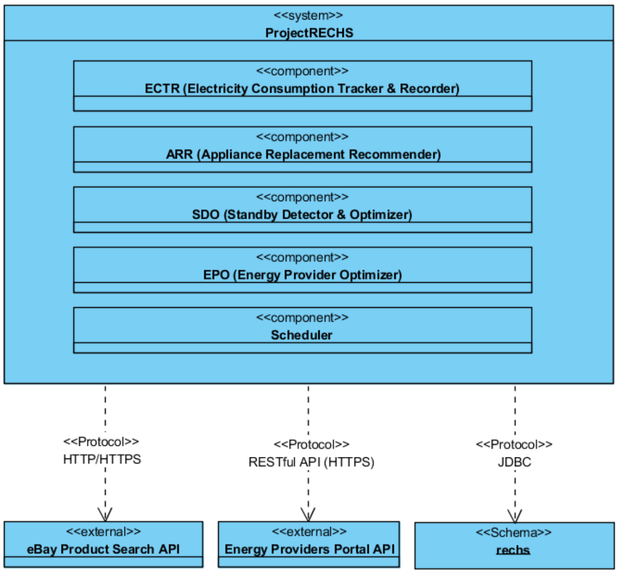

Fig. 3 System Architecture

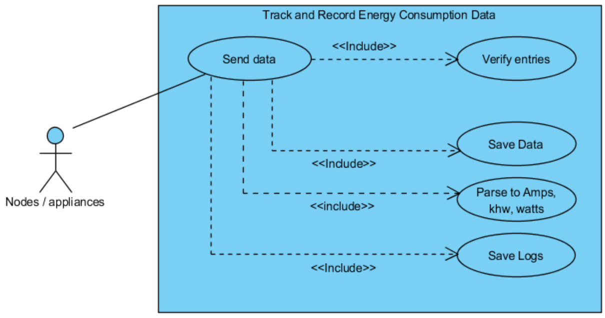

Fig. 4 Use Case - Track and Record Energy Consumption Data

During the design phase, nearly every single aspect of this project has been gone through and translated into an understandable diagram using conventional modelling techniques such as use-cases, classes model, activity diagrams and sequence diagrams. Moreover, the bird-eye database entity-relationship diagram was provided to offer an efficient and transparent basis to communicate with project stakeholders efficiently. Also, having this number of visual diagrams makes it easy for a new developer to understand the project and get involved in it efficiently and effectively. As a result of using the waterfall methodology to achieve this project, noticeable project time was used for this stage, because it is important to make sure that all the project's aspects and details are covered before starting the expensive "implementation stage" which will be covered in the next chapter.

B. Implementation

This experiment is a combination of hardware (Z-Wave compatible plug-ins) and Java Spring Boot, MySQL Database, Angular JS based software. A description of all the details of the implementation stage mainly includes: development infrastructure, hardware installation and software. Z-Wave plug-ins monitor the power consumption and regularly feeds the Microservices API with the collected information. There is also communication done from a microservice to control the plug-in to completely cut off the electricity consumption when appliances being in the standby mode. Following is a detailed description of all related components:

1) Infrastructure*:* This experiment is developed using several infrastructures platforms that made the development easier, secure, sharable and more efficient. Maven Central Repository, GitHub, Heroku cloud are among the used infrastructure components.
2) Hardware Components*:* Z-Wave plug-ins will be used to monitor the power consumption and send it to a central API. AEOTECT Z-STICK GEN5 (Fig. 7), and AEOTEC Smart Switch 6 (Fig. 8) from Aeotec Aeon Labs LTD were utilized for this experiment because it has a good reputation, low-priced, offers qualitative and accurate measurements and the vendor offers a wide range of products. Every Z-Wave compatible network needs a controller. This is necessary to establish the communication between the host (server, NAS …) and other Z-Wave compatible nodes. It has the inbuilt Z-Wave diagnostic tool and equipped with a multi-colored signal strength LED to indicate the strength of the signal between the controller and other nodes. It is also useful during the setup process to figure out the current status and get notified when errors occur. Fig. 7 shows the controller used for this project.
3) Software Components: Several components and modules were used, these include: open Home Automation Bus (openHAB) version 2.3.0, Oberasoftware ZWave Library for Java [11], RESTful based microservices farm which is shown in Fig. 9, this is built as a RESTful API, and offers many verbs categorized in several controllers to manage appliances, nodes, energy providers, authentications and users, application's heart-beats, measurements, and finally the scheduler. The frontend GUI is a combination of HTML5, CSS and JavaScript. Some particular frameworks were applied such as Bootstrap, JQuery, Charts.js. Front-end components will communicate with the Java-based RESTful API using the PHP-based Middleware. Front-End has developed with the responsive design feature. This means that it can be viewed using different platforms/hardware including Galaxy S5, Pixel 2, Pixel 2 XL, iPhone 5/SE, iPhone 6/7/8, iPhone 6/7/8 Plus, iPhone X, iPad and iPad Pro. The developed application consists of several modules, these are shown

below.

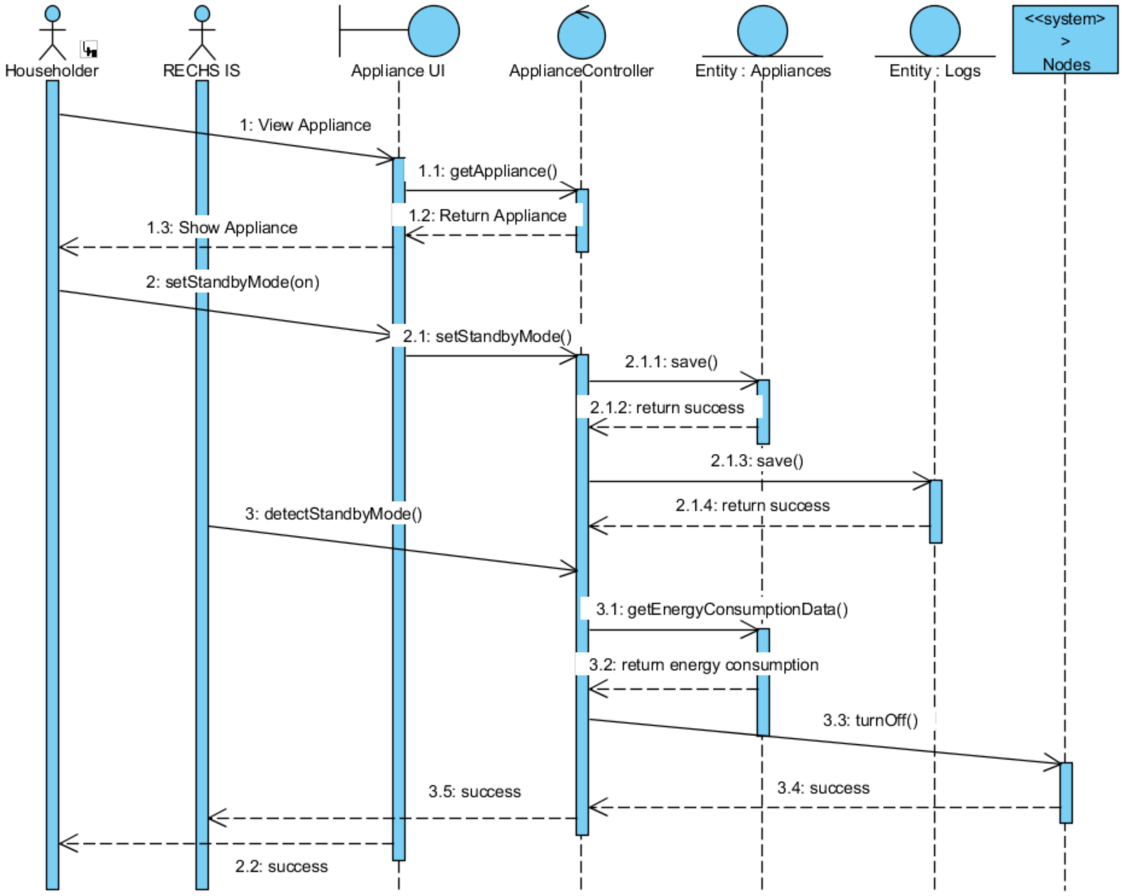

Fig. 5 Sequence Diagram - Detect Standby Mode

ECTR: Collecting the data is a fundamental part of the whole functionality. When appliances connected via end nodes to the controller, energy consumption data that include Amps, kWh and Watts will be tracked and saved to the database regularly. Gathering data for few months provides an appropriate picture of the amount of energy consumed by the measured appliance, it also illustrates the energy-consuming behaviour of the appliance, so decisions such as replacing the appliance with more efficient one or switching the appliance when its standby mode is detected, can be made. Once data are collected correctly and precisely, several functions can be offered; such as: (1) Together with eBay product search, the system will be able to suggest buying new devices. (2) Tracking will let the system to identify the standby level (in Watts). This allows the system to switch off the device once it goes in this mode. (3) This module offers different charts (Figs. 16-18) and raw data (Fig. 10) to visualize the energy consumption of some chosen appliances over the tracking period.

Energy Supplier Optimizer (ESO): As an extra feature, the householder can enter the current costs they pay for the energy provider. Using external portals, more suitable and efficient energy providers can be searched and potentially replaced. It compares the prices and services of local energy providers with the current one and suggests exchanging it when better conditions are found. An important criterion for the recommendation is the source of the generated energy. Energy suppliers who use clean and regenerative sources are highlighted and recommended. Fig. 11 shows how this module is represented in the application.

ARR: A module searches recognized online-shops (eBay product search) to search for similar products with better energy efficiency attributes and suggests the householder buying these appliances and sell old ones to reduce energy consumption. The precondition for this module is having the device’s configuration entered by the administrator. Fig. 12 illustrates it.

SDO: It tracks and indicates the standby status of appliances and cut-off the energy entirely when the standby mode is detected. This feature cannot be applied to every appliance, therefore it is important to differentiate between applicable and non-applicable devices that support this approach, for example, it can be applied to a TV because switching the TV off automatically, when it goes in the standby modus, does not cause any damage to it. However, applying this feature to a refrigerator or heating system may have hazard effects. Therefore, administrators are required to particularly assign the device as applicable (Fig. 19). By default, all devices are marked as non-applicable. This module's results are illustrated in Fig. 13.

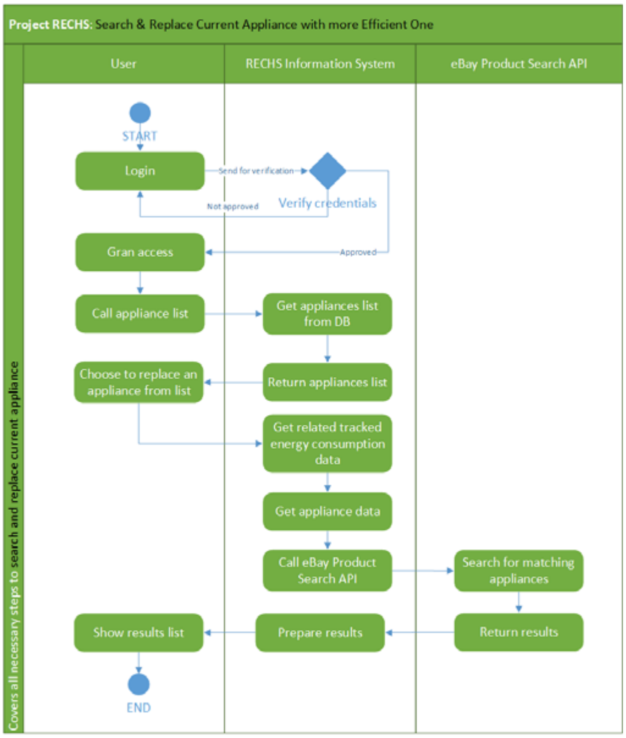

Fig. 6 Activity Diagram - Replace current appliances

Fig. 7 AEOTECT Z-STICK GEN5 Controller

Fig. 8 AEOTEC Smart Switch 6

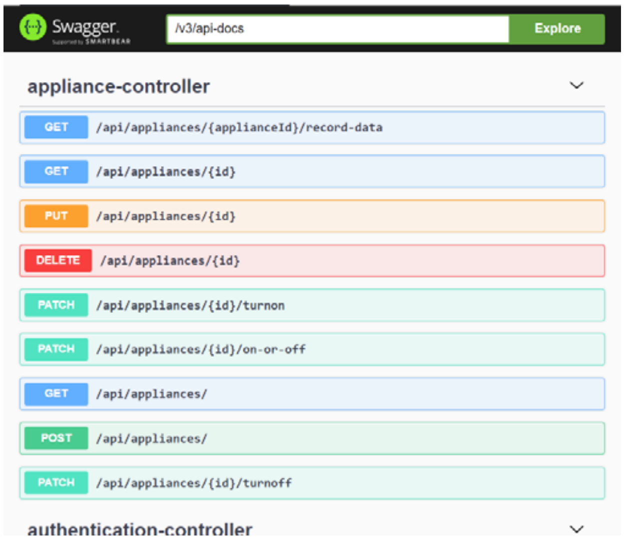

Fig. 9 Swagger Documentation - Microservices Farm

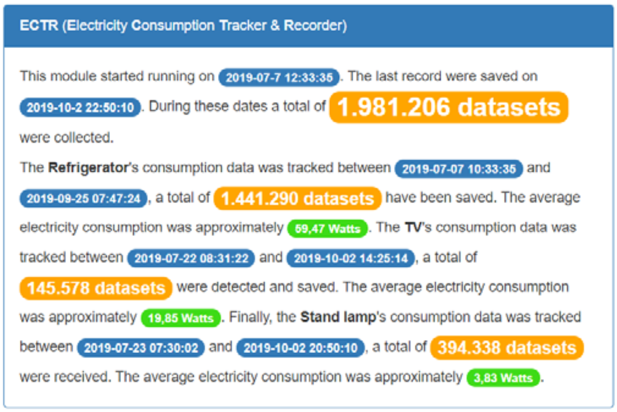

Fig. 10 ECTR

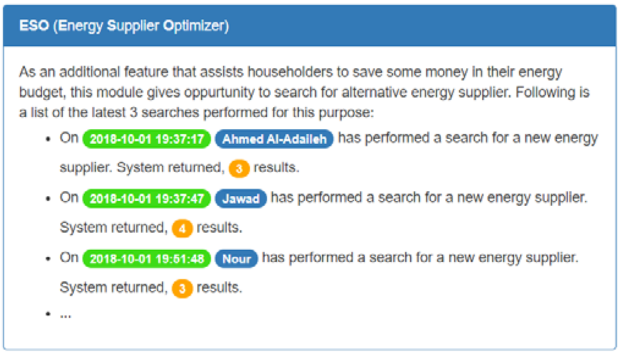

Fig. 11 ESO

Schedular: This module is designed to create, edit and delete schedule for all three appliances to switch it on/off. Scheduling the working times of devices has a direct impact on the consumed energy. Following are some examples of real-life conditions: 1) High energy consuming devices such as under-sink immersion heater with cylinders which usually runs 24 hrs to keep the water warm and ready for use, can be switched off during the night, and when occupants are outside the house. 2) Another example is offering a way to control the periods when teenagers or kids are allowed to run their gaming stations, PCs or laptops. This can be achieved by using the schedular to switch these devices off. It also offers to shut down the WiFi service inside the household by switching-off the router. Fig. 14 shows the scheduler management details.

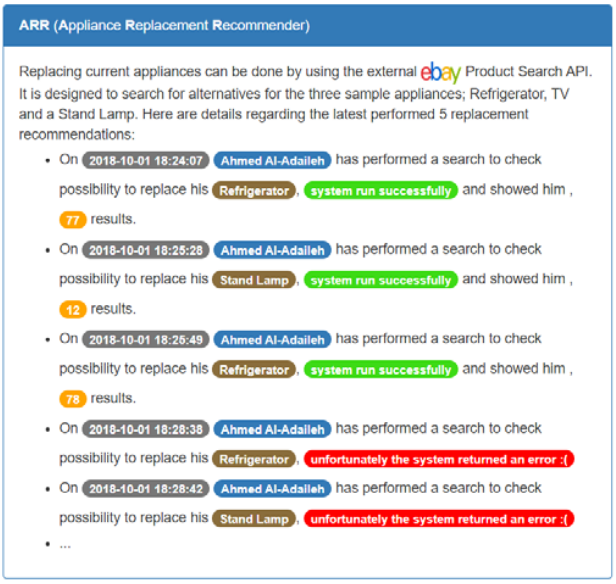

Fig. 12 ARR

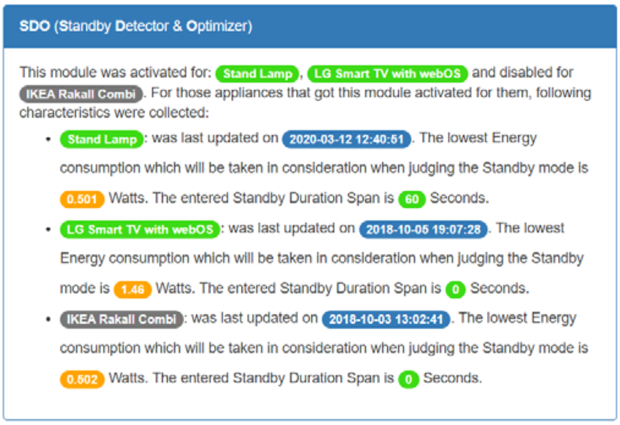

Fig. 13 SDO

The experiment considered three appliances from the household; Refrigerator, TV and ordinary light bulb. These devices can be configured via the GUI as shown in Fig. 15.

Building this experiment went through several stages; these are divided into two main areas: hardware and software. This section included a detailed overview of the hardware area, including which devices were used and why. The main focus was put on the devices from the AEOTEC By AEON LABS. Also, it includes a detailed explanation of the used software: the open-source openHAB and self-made Project RECHS. The Front-End of both software were shown and explained with screenshots. Since the database plays an essential rule in any application, a detailed explanation has been provided in this chapter including tables, relations, fields and indexes. The next chapter "Testing" will focus on making sure that all features are properly done and matching the initial user requirements and the design aspects.

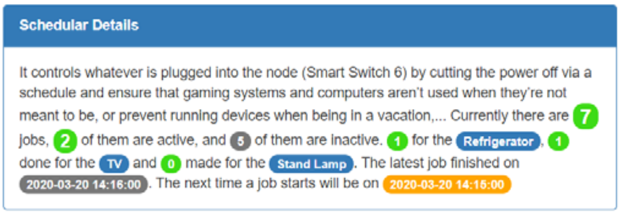

Fig. 14 Scheduler Management Details

C. Testing & Evaluation

Testing software is a challenging task because testers must exactly have a clear idea about the initial user requirements and must accompany and be involved during the various project stages, so they gain an in-depth understanding of the functionality. Testers must also have a wide knowledge regarding the used techniques and technologies, also must know how to report mismatching, bugs or fatal errors. In this chapter all testing aspects will be covered, including different testing types, related test cases, tools and methodologies, and finally a brief explanation how to handle a change or report a bug for this project. These are Alpha Testing, Accessibility Testing, Back-end/Database Testing, Browser Compatibility Testing, Integration Testing, Load Testing, Monkey Testing, Unit Testing. Testing is one of the most critical tools to ensure high project assurance. In reality, there are dozens of different tests which can be applied. Therefore, it is essential to decide which test to consider depends directly on the nature of the project. In this experiment, 8 different tests were chosen and applied: Alpha testing, Accessibility testing, Backend/database testing, Browser compatibility testing, Integration testing, Load testing, Monkey testing and Unit testing. Also, two additional sections are included to describe the tools, techniques and technologies used in the project in general, also the way how change requests and bug are reported. As a result of all performed tests, most of the known bugs were fixed, and the application is matching the original user requirements. In the next chapter an overall conclusion, future work, project problems and challenges will be described and explained.

TABLE I
AVERAGE ENERGY CONSUMPTION IN WATTS

Appliance	Period	Average energy consumption
Refrigerator	2019-07-07 10:33:35 - 2019-09-25 07:47:24	119,47 kWh
Television	2019-07-22 08:31:22 - 2019-10-02 14:25:14	91,85 kWh
Bulb	2019-07-23 07:30:02 - 2019-10-02 20:50:10	6,83 kWh

Observing the energy consumption (in kWh) for the three devices reveals the average energy consumption, these are mentioned in Table I. To verify these numbers the system offers splitting it up into daily usage rates. Fig. 16-18 show this daily basis distribution.

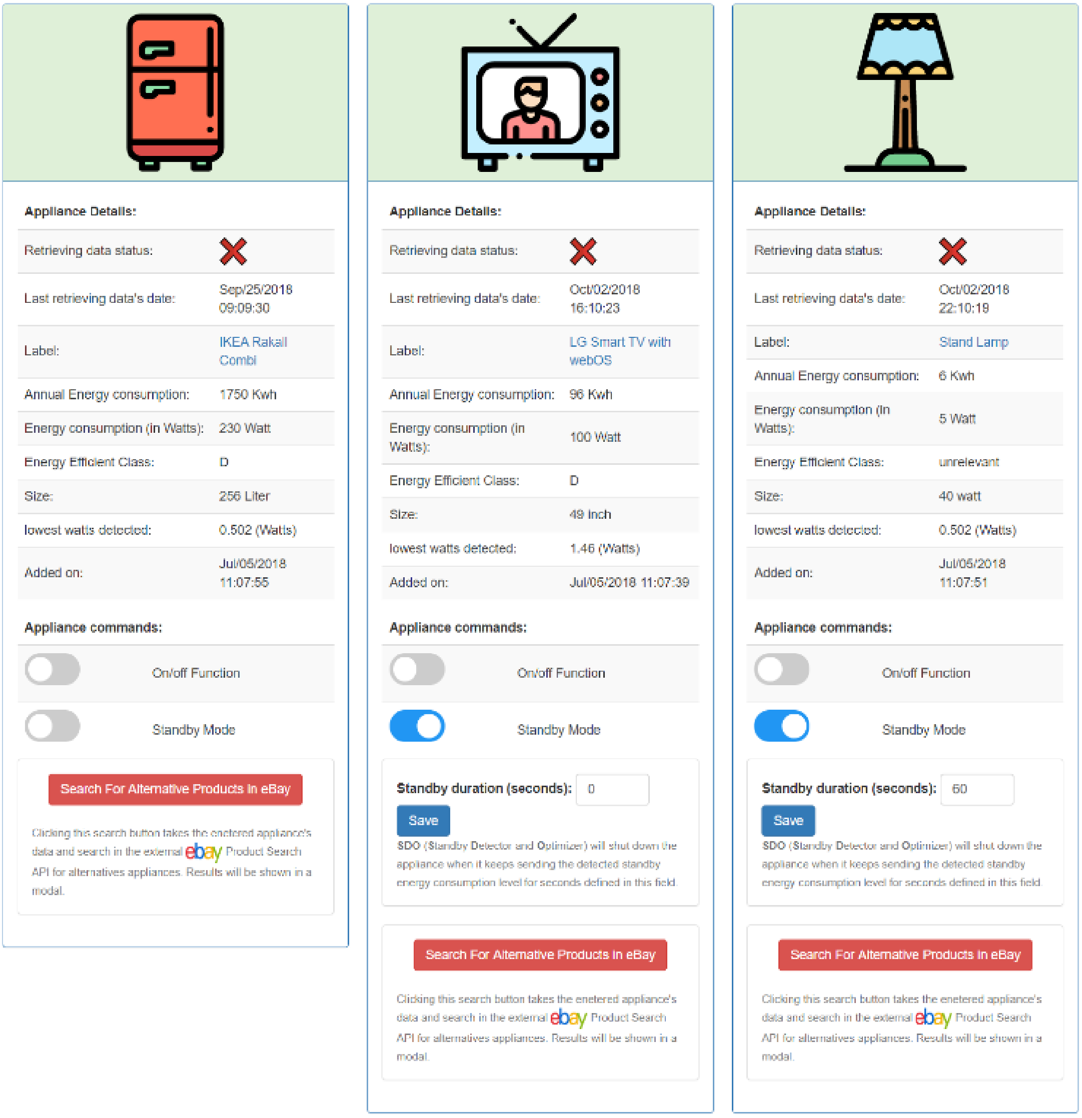

Fig. 15 Project RECHS - Appliances Overview

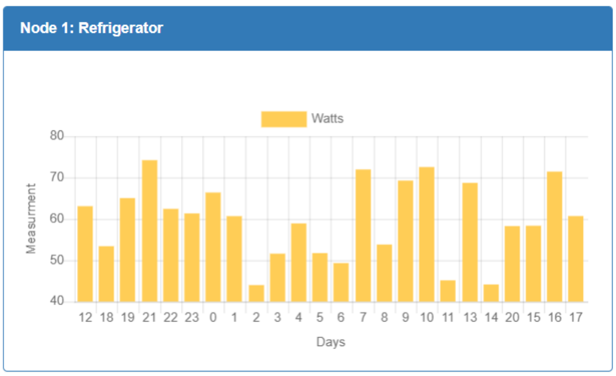

Fig. 16 Refrigerator Daily Energy Consumption on Daily basis

As we see in Fig. 17, the refrigerator consumption is irregular; therefore it is not suitable for any scheduling possibilities. However, the TV behavior is different; it follows a certain paradigm, switched off between 10 PM and 7 AM. The same behavior is shown by the bulb. These outputs assist the administrator to better decide setting up a schedule or to activate the SDO. Table II illustrates the power consumption in kWh according to the energy labeling related to a reference consumption based on the storage volume and the type of both TV and Refrigerator EEI [12]. The light bulb energy consumption is indicated in size.

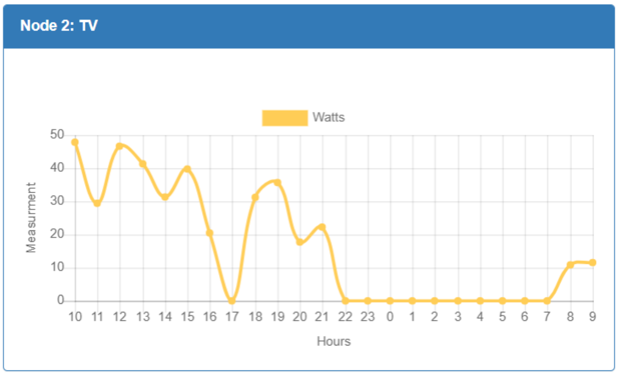

Fig. 17 TV Daily Energy Consumption on Daily basis

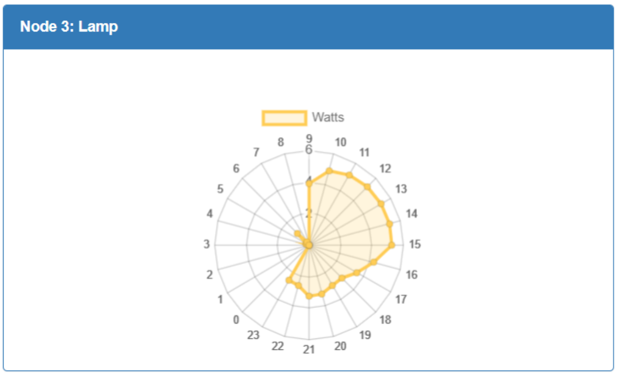

Fig. 18 Light Bulb Daily Energy Consumption

TABLE II
ENERGY LABELS AND KWH

Appliance	Energy Label	kWh
Television	A+++	<10
	A++	<16
	A+	<23
	A	<30
	B	<42
	C	<60
	D	<80
	E	<90
	F	<100
	G	>100
Refrigerator	A+++	<22
	A++	<33
	A+	<42/44
	A	<55
	B	<75
	C	<95
	D	<110
	E	<125
	F	<150
	G	>150
Bulb	As indicated in size	

Now we have all parameters required to evaluate the energy consumption and thus to take actions; these are 1) The measurement of the real energy consumption of the three devices over a reasonable period (approximately three months). 2) The energy labelling per device and 3) the lowest energy consumption measured at all. Using all these parameters we can apply two strategies to reduce the energy consumption: 1) Activating the standby mode, 2) Searching for alternative products using external e-commerce portals, and 3) Allowing scheduling the work periods of household appliances to prevent unpermitted or unneeded usage of appliances, e.g. prevent children/teenagers to use the high-energy-consuming gaming server over the night, or switching off the under sink water heaters.

V. ENERGY CONSUMPTION REDUCTION STRATEGIES

The main strategies followed in this research are: Standby detector and replacing appliances. The Standby-Mode strategy: is based on measuring the lowest energy consumption of a device over a long period, then defining the standby duration in seconds manually using the administration GUI. When the system recognizes that this device is consuming the lowest energy level (which is measured over a long period) for the defined standby duration, it shuts down (cut off the energy) for this device. This will bring an immediate energy consumption; however, the amount of saved energy is not huge, and it cannot be applied on all devices, therefore the administrator should activate this function for every device explicitly. Fig. 19 shows this part in the GUI. The second strategy is searching for alternative devices strategy. A manual search can be performed to find out whether replacing the current device with another one similar in attributes but with less energy consumption is a good idea. Some aspects must be considered; such as the price of the new device, the price of energy in the area, the price of the old device (if sold as second-hand), finally the ROI $[ROI = \frac{Net\ Profit}{Total\ Investment}\ x\ 100]$ which is the ratio of a profit or loss made in a fiscal year expressed in terms of an investment; this defines the time needed to pay back the costs of the new device after a certain period due to the saving of the energy costs [13]. The third strategy based on offering a possibility to schedule the working hours of an appliance: such a function makes it possible to restrict the working hours according to needs. This can be very effective in some devices such as the under-sink heaters. Those heaters keep working 24 hours by heating the water when the temperature drops below a predefined point. This feature may make sense during the day, or when the occupants are at home but do not make sense during the night, or when people not at home. Moreover, it offers more control on some entertainment devices used by under-aged allowing a higher degree of parental control and ultimately reduction of energy consumption.

As indicated before, after running the system for about three months, a reasonable amount of data has been collected, so energy reduction strategies can be applied. For this purpose, we have to choose between the three devices: TV, refrigerator and bulb. Due to the fact that the refrigerator is not suitable to activate the standby-mode, we will consider taking the TV as an example and start applying these strategies and discuss outputs. According to the measured energy consumption data the lowest measured energy consumption was 1.46 Watts (or 0.01314 kWh), and the defined standby duration was set as 10 seconds. After activating the SDO, the daily energy consumption of the TV was reduced by 7,0956 kWh over two months, considering the local energy price which is 0.2961 €/kWh, the total reduction is 2,1€ within this period. Applying this strategy on different devices in the household such as stereo, NAS, coffee machines … etc. may lead to remarkable savings.

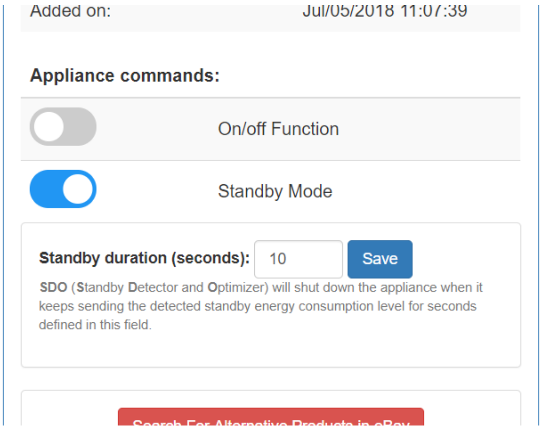

Fig. 19 Standby Control Box

The second strategy which is related to replacing the device by buying a new one and selling the old device will be again applied to the TV. In this case study, we are dealing with an "LG Smart TV with webOS", according to the manufacturer inputs, this device has the following attributes: the energy efficiency class is A+, the annual energy consumption is 96 kWh, or 69 Watt. Audio output 10W, and the screen size is 49 inch [14]. According to the real measurements, the average energy consumption was 70.39 Watts, all measured Watt values under 10 Watts were ignored due to standby-mode detection, see Fig. 20.

When running the search function, the external API (eBay) [15] returns the results shown in Fig. 21. The system suggests several alternatives, in this case we will consider the first choice: "MEDION X15502 Fernseher 138,8cm/55" Zoll 4K UHD Smart TV HDR10 Dolby Vision A++"

TABLE III
COMPARISON OF CURRENT TV "LG" AND SUGGESTED TV "MEDION"

Attributes	LG Smart TV	MEDION Smart TV
Screen Size	49"	55"
Price	315.99€	369,99€
Energy Label Class	A+	A++
Energy Consumption (Watts)	69	50
Energy Consumption (kWh)	96 kWh / Annum	87 kWh / Annum
Audio	Dolby Digital, Virtual surround Plus	Dolby Vision HDR, DTS Sound

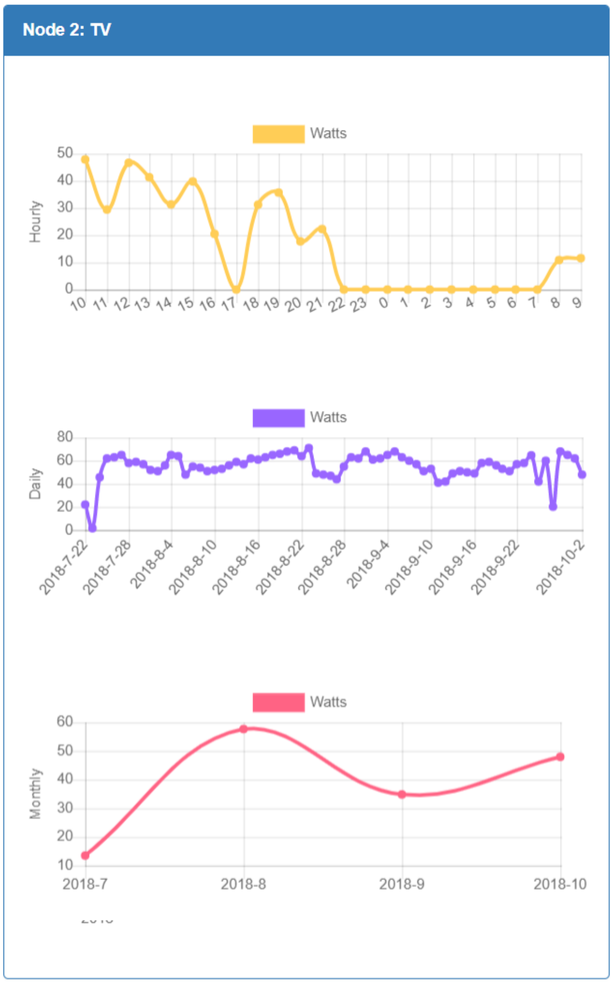

Fig. 20 TV's Hourly, Daily and Monthly Energy Consumption

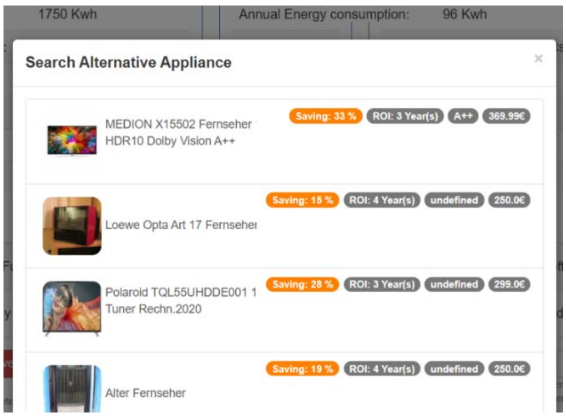

Fig. 21 eBay Search Results for a TV

As Table III suggests, a comparison between the current LG TV and the suggested one from MEDION reveals that by substituting the TV the ROI will be about 33%, calculated as:

$$TV\ Average\ Daily\ Operating\ Time\ (ADOT) = 6\ hours$$
$$Average\ Electricity\ Price\ per\ kWh = 0{,}2961\ €\ per\ kWh$$

$$Energy\ Cons.Diff.(Watt) = 69 - 50 = 19\ Watt$$
$$Energy\ Cons.Diff.(kWh) = 19\ x\ ADOT = 1{,}14\ kWh$$
$$Total\ Saved\ Money = Net\ Profit$$
$$= (365\ days)\ x \left(0{,}3861 \frac{€}{kWh}\right) x\ (1{,}14\ kWh)$$
$$= 123{,}2072\ €$$
$$ROI = \frac{Net\ Profit}{Total\ Investment}\ x\ 100 = \frac{123{,}21\ €/Annum}{369.99\ €}\ x\ 100 = 33{,}30\%$$

This means that after 3 years the initial costs of the new TV will be covered by the difference of the energy consumption costs. This period will be much shorter when the new TV initial price is lower, or when the difference of the energy consumption is higher. If the old device is sold as second-hand, the ROI will be higher and thus the time will be much lower than the calculated 3 years. Important to mention that selling the old devices over eBay is a profitable approach for the household occupants because it reduces the ROI period by gaining some cash. Although it is meant to sell the old nonefficient appliances over eBay, to make the process a bit more attractive for household occupants by reducing the ROI period and gaining some cash, and offer those appliances for recycling companies and for spare-parts-donor, the framework cannot prevent selling and running those devices in another household, which does not serve the main target of reducing the energy consumption. As prophylactic sanction could be labeling those devices as "Only-For-Recycling" or "Not-Permitted-To-Run".

The third strategy is simply achieved by setting up a schedule to switch the device ON/OFF. In Fig. 22 is an example of such a schedule to maintain the under-sink operating periods. In this schedule the device will be switched ON daily from 06 AM to 10 PM. Since this type of devices keep running almost the whole day to maintain the water's temperature. When applying such a technique, the energy consumption will be dramatically reduced during night.

Following are the calculation of a normal under-sink heater:

$$Immersion\ heater\ power\ rating = 6\ kW$$
$$Tank\ capacity = 120\ Liters$$
$$Time\ to\ heat\ water = 125\ minutes\ per\ tank$$
$$Cost\ of\ electricity = 1{,}88€\ per\ tank = 1373€\ per\ year^{*}$$

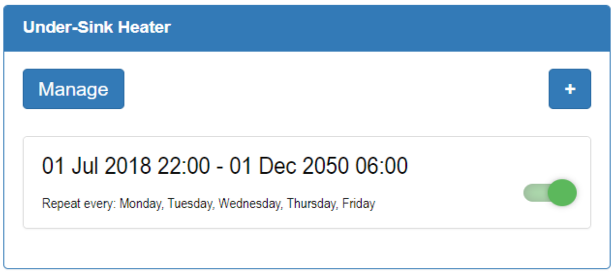

Fig. 22 Under-Sink Heater Schedule

The previous calculation is based on heating mains water from 15° to 60° (recommended for hot water storage) using the rate of 30c/kWh. According to [16] "Totals do not include keeping the tank at the required temperature between heating cycles and assume 100% efficiency. Per year costs are based on 2 heating cycles per day". Now if we apply this approach to the under-sink heater, the total annual energy consumption will be reduced by approximately 1/3, since the heater will be totally shut down for 8 hours every day. In numbers this means:

$$Heater's\ Daily\ Operating\ Time\ (DOT) = 16\ hours$$
$$Heater's\ Saved\ Energy\ Costs = \frac{1373\ €}{3} = 457{,}67€\ anuually$$

VI. Conclusion and Future Work

Living in a limited energy resources world obligates humans to become smarter while consuming power in every field in their lives. As previously mentioned in several statistics and studies [1], [5], [2] the household sector is one of the biggest energy consuming areas, therefore reducing the consumed energy in this field will have a huge impact on the overall energy consumption and ultimately assist the world to become a better place to live. RECHS Framework is an attempt in this direction by applying passive and active methods. Project RECHS applies several mechanisms to achieve this goal, these are: (1) Measuring and tracking energy consumption. (2) Offering possibility to search & replace high-energy-consuming household appliances. (3) Shutting down household appliances when standby mode is detected. (4) Allowing scheduling the work time spans of household appliances to prevent unpermitted usage of appliances (e.g. prevent children/teenagers to use the high-energy-consuming gaming server over the night). (5) Offering possibility to search & replace current energy provider, to reduce the households spent budget. The case study applied for the TV and under-sink water heaters shows a possibility of energy consumption reduction by 30%.

The future work may include several approaches such as; 1) increasing the accuracy of the measurements by applying more reliable and advanced hardware. 2) offering the collected valuable data to manufacturers, governmental services, energy suppliers and research and development establishments such as universities, research centres. 3) applying this framework on a large number of households by offering a cloud-based solution, applying strict security and privacy aspects will accumulate the gains and the savings. 4) binding further external APIs such as weather forecast APIs, traffic APIs will add a more accurate and more precise attribute to the architecture and allow it to consider the surrounding environment when dealing with appliances inside the household.

Acknowledgment

In the Science, Engineering and Computing Faculty in Kingston University - London, the author thanks Prof. Dr Souheil Khaddaj who offered his valuable knowledge and accompanied the author during this research. Without his extensive support and valuable feedback, this paper would not reach any advanced stage.

REFERENCES

[1] Bundesverband WindEnergie e. V., "Statistics," 06 March 2020. (Online). Available: https://www.wind-energie.de/english/statistics/.

[2] Eurostat, "Energy consumption in households," eurostat Statistics Explained, 01 May 2019. (Online). Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households. (Accessed 11 March 2020).

[3] W. Shepherd and L. Zhang, Electricity Generation Using Wind Power (Second Edition), Singapore: World Scientific Publishing Company, 2017.

[4] S. Malla, "CO_2 emissions from electricity generation in seven Asia-Pacific and North American countries: A decomposition analysis," Energy Policy, vol. 37, no. 1, pp. 1-9, 2009.

[5] W. Liang and Roskilly, "Reduce Household Energy Consumption Using Passive Methods," Energy Procedia, vol. 75, pp. 1335-1340, 2015.

[6] Independent Science & Engineering Support, "Wall Calculator for R-values and U-factors including checks for moisture control," (Online). Available: https://www.appliedbuildingtech.com/fsc/calculator. (Accessed 10 March 2020).

[7] Alliant Energy, "PowerHouse: 101 Ways to Save Energy," (Online). Available: http://www.powerhousetv.com/Energy-EfficientLiving/Energy-savingsTips/027471. (Accessed 10 March 2020).

[8] V. F. C. Servant-Miklos, "Problem solving skills versus knowledge acquisition: the historical dispute that split problem-based learning into two camps," Advances in Health Sciences Education, vol. 24, pp. 619-635, 2019.

[9] E. Griffith, "How to Measure Home Power Usage," 20 April 2017. (Online). Available: https://uk.pcmag.com/consumer-electronics-reviews-ratings/76699/feature/how-to-measure-home-power-usag0065. (Accessed 10 March 2020).

[10] G. Brandon and A. Lewis, "Reducing household energy consumption: a qualitative and quantitative field study," Journal of Environmental Psychology, vol. 19, no. 1, pp. 75-85, 1999.

[11] R. d. Vries, "Oberasoftware ZWave Library for Java," 16 January 2016. (Online). Available: https://github.com/oberasoftware/zwave. (Accessed 12 March 2020).

[12] EEI Edicson Electric Institue, "EEI Edicson Electric Institue," EEI Edicson Electric Institue, (Online). Available: https://www.eei.org/Pages/default.aspx. (Accessed 13 March 2020).

[13] M. Menezes, S. Kim and R. Huang, "Return-on-investment (ROI) criteria for network design," European Journal of Operational Research, vol. 245, no. 1, pp. 100-108, 2015.

[14] "LG," (Online). Available: https://www.lg.com/uk/tvs/lg-49LJ594V. (Accessed 20 03 2020).

[15] "eBay Inc.," (Online). Available: http://developer.ebay.com/devzone/shopping/docs/callref/findproducts.html. (Accessed 12 02 2020).

[16] sust-it, "Electric Immersion Water Heater Running Costs Calculator," TurnRound Limited, (Online). Available: https://www.sust-it.net/immersion-heater-energy-calculator.php (Accessed 26 10 2020).