¿Track: A Residential Energy Monitoring System Tailored to Meet Local Needs

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Abstract—The Kingdom of Saudi Arabia, like many other Gulf Council Countries, is lately experiencing a very rapid population and industrial growth, which results in an increasing demand for energy. To meet this growing demand, the GCC too is transitioning towards a smarter electricity grid with increased penetration of renewable sources. However, all agree that the success of such a shift in paradigm also depends on demand side management, most of energy demands coming for residential area. Providing residents with real-time feedback on their energy consumption is a promising way to promote energy saving behavior through an increased awareness. This paper outlines the design and development phases of a residential energy monitoring system that has been tailored to meet local needs, that is to say a non-intrusive system with a user friendly interface available both in English and Arabic endowed with an alert system providing real-time consumption information, as well as energy saving and awareness tips.

Keywords—*home energy management system; energy monitoring system; wireless sensor network; KSA; GCC*

I. INTRODUCTION

The Kingdom of Saudi Arabia (KSA) is blessed with an abundance of energy resources. It has the world's largest proven oil reserves; the world's fourth largest proven gas reserves, and is the world's 20th largest producer and consumer of electricity [1, 2]. As stated in [3], on a per capita rate, Saudi Arabia has very high electricity consumption, mainly due to the improvement in living standards. Also, KSA is experiencing both population and industrial growth, causing a huge demand for power and especially electricity. Combined with these two local factors, the very high emission rate of CO_2 in the region makes it a National priority to reduce energy consumption. All agree that society needs to use existing electrical power more efficiently [4]. One way of making that happen in residential area is to inform the consumer about their energy usage. In fact, several experiments on energy monitoring systems shows that the visualization of power consumption could reduce the entire energy consumption of residential areas by 10–30 % [5]. Currently, people only know their total monthly consumption, but a real-time load monitoring does not exist.

This study outlines the design, development, and implementation phases of a residential energy monitoring system that has been tailored to meet local needs, that is to say:

- an enhanced visualization system providing real-time consumption information (e.g. total house consumption, or room / appliance consumption) through a user-friendly interface available both in English and in Arabic;
- an educating interface, increasing energy awareness of users or simple visitors through a set of energy saving and awareness tips;
- an interactive solution with a warning mechanism where it is possible to set up thresholds on monitored parameters to help detect alarming situations and alert the user through an alarm message (e.g., sms, e-mail);
- an adaptive system that can work with any type of building, and corresponding billing rates;
- a non-intrusive solution that does not necessitate construction / hard-wiring;
- an efficient processing of past data to enable comparison of past and current consumption, besides comparison of various sensors current consumption;
- an accessible system, reachable from anywhere, from any device (e.g. smartphone, PC);
- a highly secure system, with various actors having various privileges;
- a low-cost system itself consuming low power.

II. SYSTEM OVERVIEW

A. General Description

The proposed system, iTrack, is composed of a software and a hardware component. The hardware part consists of a non-intrusive wireless sensor network measuring the current and voltage in selected places, and a router sending measurements to the system database remotely located. The software analyzes the gathered data and provides a visual representation of the home electricity consumption as a web-based application that is reachable from anywhere. In order to correctly calculate energy consumption, the system needs to communicate with the Saudi Electricity Company (SEC) database to get the consumption segment information, as electricity charges in the KSA depends on the building type (e.g. residential, commercial), but also on the amount

consumed [6]. The user can set a maximum consumption limit either for the house as a total consumption, or per room / appliances. ITrack sends an alert message when the current consumption get close to the limit, through a mobile messaging service. The system is intended for everyone but especially for the Saudi population from novices to expert in different ages. Therefore, the system provides both Arabic and English interfaces, through an automated translation of the English phrases to Arabic. Figure 1 shows the context diagram of the system with the external entities that contribute to its operation.
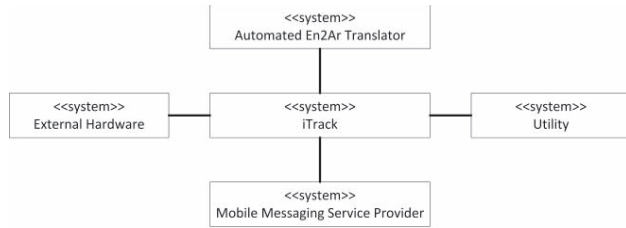

Fig. 1.   Context Diagram for the iTrack System

B. Use case diagrams

The system provides functionalities in three aspects:
1.   admin aspect,
2.   home-resident aspect and
3.   guest aspect.

At the admin aspect, adding, deleting and/or editing on the features of his/her home are enabled for the system user. The admin can also set consumption limit, either for the whole home, or per room / appliances, to help control the energy consumption. At the home-resident aspect, only the viewing functionalities are available. These viewing functionalities include accurate measurement of energy consumption and calculation of user electricity bill, or viewing consumption limits (Figure 2). At the guest aspect, only browsing the website, discovering its functionality and sign up into the website are available. Figure 3 shows the use case diagram established for each actor.

III.   PROPOSED SYSTEM ARCHITECTURE

Among several web-based architectures that can be utilized for our web-based system (e.g. layered architecture, message bus architecture, N-tier architecture, object-oriented architecture, service-oriented architecture) [7], client-server and N-tier architectures are preferred.

Client-server architecture is a computing model where one or more computers act as a clients and one computer acts like server, and all clients request services from the server [8]. The server hosts the software system and the system database as well. Many users in different places, may access the server using different devices at the same time, and the system security should be high, since the user information is saved in a centralized database.
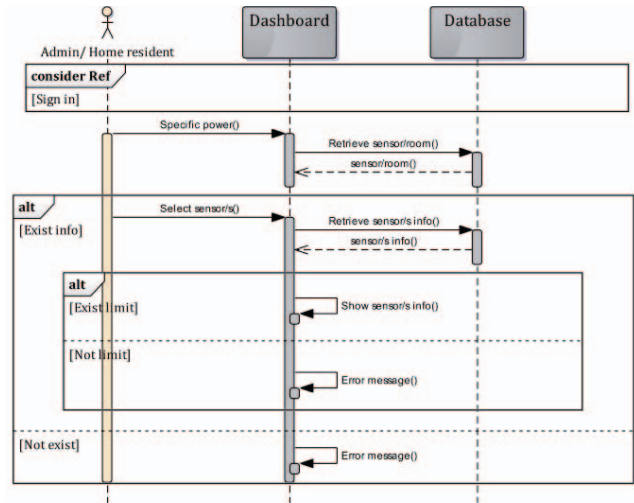

Fig. 2.   View Consumption Limit (Each) Sequence Diagram
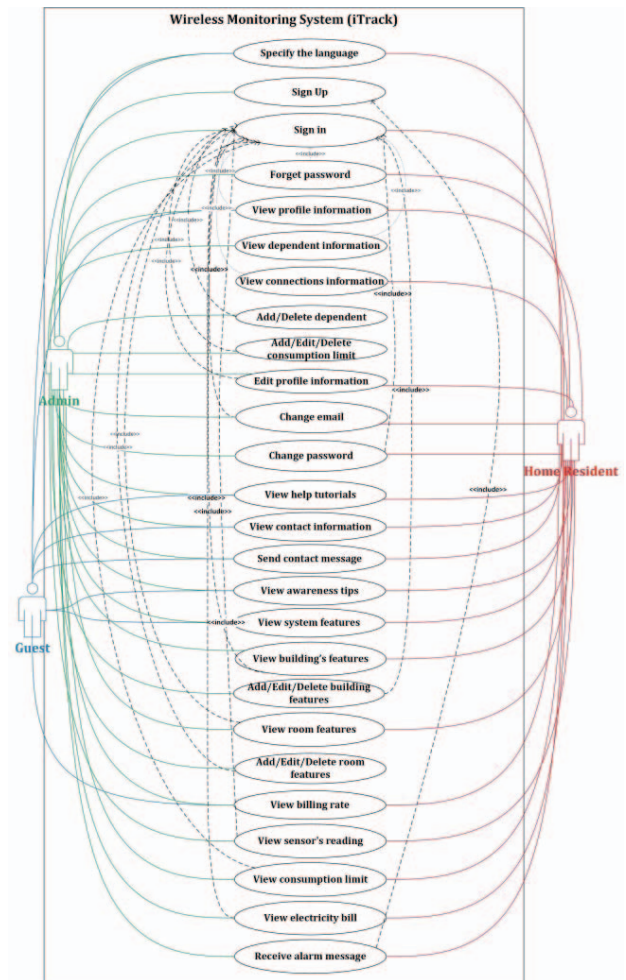

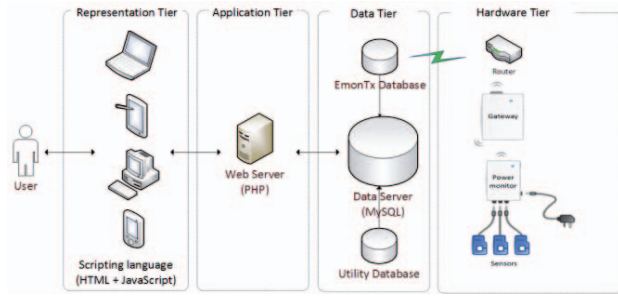
Fig. 3.   Use Case Diagram

Fig. 4. Architectural Design of the iTrack System

Figure 4 shows the architecture of iTrack. The system architecture consists of 4-tiers: representation tier, application tier, data tier, and hardware tier. First, the representation tier is the website of the system working on the web browser in the user device. Second, the application tier is the web server that is hosting the system website. Third, the data tier is the data server that is storing the system databases. Finally, the hardware tier is the hardware components that sense the needed data for calculating the power consumption and sends them to the database in the previous data tier.

A. Hardware architecture

The hardware has three main components: the sensor nodes that interface with the electricity circuit using non-invasive clip on CT current sensors and an AC-AC Voltage adaptor to provide a voltage signal, a gateway to link transmitter and display units to the web, and a regular home router. The sensor nodes connect with the gateway through a wireless adapter. The gateway then connects to the Internet using the regular home router to transfer the data to the iTrack database.

B. Database architecture

As shown in Figure 5, the system consists of eight entities, eight binary relationships; called binary because each relationship is associated with two entities only, and the associated attributes with each one of them (each entity and each relationship) which are illustrated by oval shape. The line under some attributes means that these are the primary attributes (the primary keys). Each entity is illustrated by rectangular shape, which are (Account, User, Role, Building Type, Building, Consumption Range, Room, and Room Power), and each relationship is illustrated by diamond shape, which are (four 'Has' relationships, "Contain", "Create", "Own", and "billing rate "relationships). Each user has only one account; which includes the ID, user email and the password of the user which means that each account is for a single user only. Each user has exactly one role; includes the ID and the name of the role, while each role may have a wide range of users from one to many. Each user may own from zero to many buildings while each building should be owned by one to many users, the admin and the home resident. Each building has an ID, an activation key and a name and exactly one type, which includes the ID and name, while each type is for zero to many buildings. Each building's type has one to many consumption ranges with the corresponding price for that

range while each consumption range is for one to many buildings. Each consumption range has an ID a start range and an end range. Each building contains from one to many rooms while definitely each room is contained in exactly one building. Each room has its ID, name, description, isMain, to identify that the room is utility room or not, and limit. Each room has one to many rooms energy while each room energy is for one room only. Each room energy has a power and time.
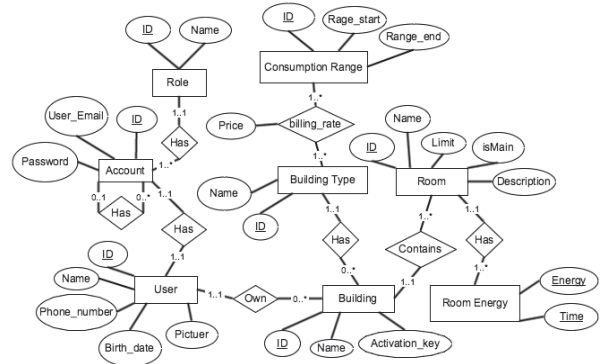

Fig. 5. ER Diagram of the System's Database

As shown in Figure 6, each building's type has one to many consumption ranges with the corresponding price for that range while each consumption range is for one to many buildings. Each consumption range has an ID a start range and an end range.
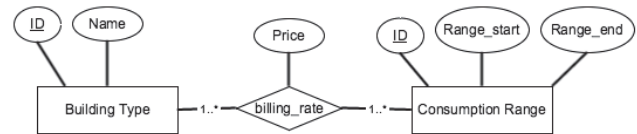

Fig. 6. ER diagram of the External Database

C. Software architecture

The iTrack software is developed using Model View Controller (MVC) architecture. The Model classes are used to hold and encapsulate the data coming from iTrack database. The use of model classes eases the access and transfer of objects between pages. The design of the model classes is a match to the database mapping presented in section III.B. Figure 7 shows the model classes of iTrack. The control classes are the heart of iTrack. They are the place where all the functionalities are implemented. The iTrack control classes house the logic and control the flow of information from/to view interfaces. Using MVC pattern provides easy maintainability, for example profile functionality can easily be changed by only changing that function in the profile control class.
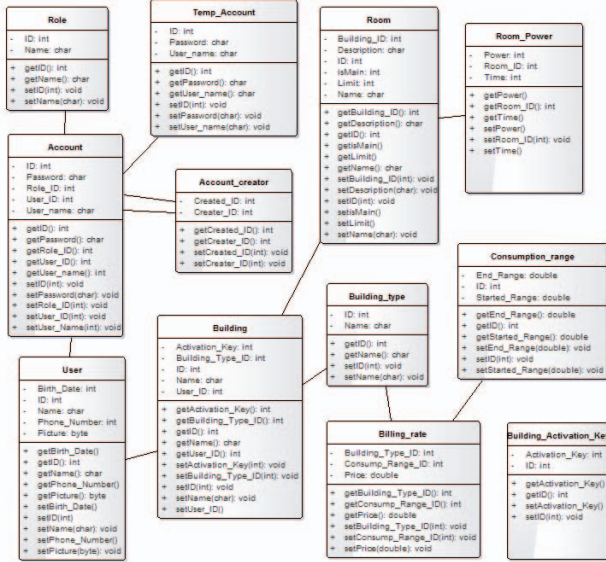
Fig. 7. Model Classes Diagram

For illustration purpose, Figure 8 shows the internal structure of the individual control class for Dashboard control.
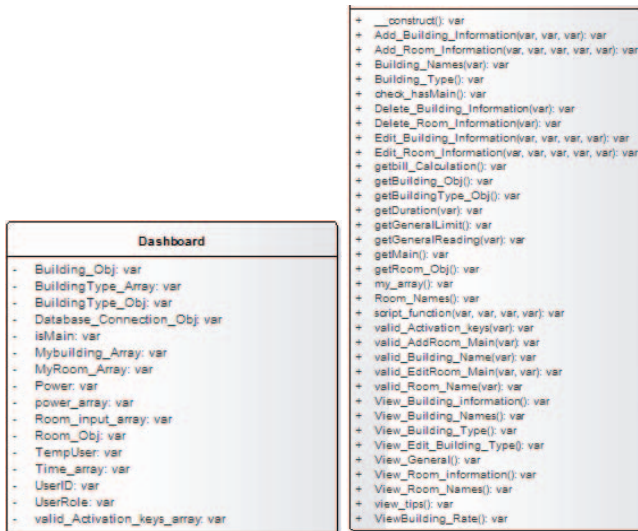
Fig. 8. Dashboard Control Class Diagram

D. Interfaces architecture and design

The interfaces of iTrack system should be clear, user-friendly and attractive. In order to achieve that, the design of iTrack interfaces has been based on the eight golden rules:

- Strive for consistency: all the interfaces components like colors, fonts, layout, menus, should be consistent.
- Cater to universal usability: recognize the user characteristic of iTrack system like novice or expert, education and age range.

- Offer informative feedback: provide a system feedback after each interaction between the iTrack users and the system.
- Design dialogs to yield closure: give an indication about user action if it is completed or failed.
- Prevent errors: design the system in a way that users should not be able to make major error by minimizing the typing input and making the user to choose from menu, gray out the unneeded field, give clear messages and instructions.
- Permit easy reversal of actions: give the user the ability of undoing actions.
- Support internal locus of control: design the system in a way that makes the user feels like he/she is controlling the action.
- Reduce short-term memory load: design the system in a way that does not require the user to recall information from previous interface.

The iTrack system has 12 interfaces: home, about, awareness tips, change email, continue registration, dashboard, forget password, help tutorial, profile, reset password, system features and verify email, and functionality of some of these interfaces differs according to the user type (Admin, home resident and Guest).

For all system user:
- The user should be able to navigate to other interfaces from the home interface. Also, the user should be able to see advertisement area.
- The user should be able to see the iTrack team members contact information on the about interface.
- The user should be able to send email to iTrack website on the about interface.
- The user should be able to see the general, safety and saving energy tips on the awareness tips interface.
- The user should be able to see the system features on the system feature interface.
- The user should be able to watch help videos on the help tutorial interface.
- The user should be able to see the consumption range coming from the utility database on the dashboard interface (electricity bill tab)

For the guest of iTrack website:
- The guest should be able to see dummy dashboard to demonstrate what the system will provides to him/her if he/she become a member.

For the admin of iTrack website:
- The admin should be able to sign up to the system on the sign up interface.
- The admin should be able to manage his/her profile by:
  - View his/her information
  - Add/delete his/her dependent

- Modify his/her information like: profile picture, full name, birth date, phone number, change password and change email.
- The admin should be able to manage his/her building information on the dashboard interface by:
  - Add building information (building type, name and activation key), edit building information and delete building information.
  - Add room information (room name, room description, room limit and main sensor), edit room information and delete room information.
  - View the consumption information (graph that show the consumption habit, the percentage of the consumed limit, bill calculation).

For the home resident:

- The home resident should be able to continue registration after his/her admin added him/her on the continue registration interface.
- The home resident should be able to manage his/her profile by:
  - View his/her information
  - View his/her connections.
  - Modify his/her information like: profile picture, full name, birth date, phone number, change password and change email.
- The home resident should be able to View the consumption information (graph that show the consumption habit, the percentage of the consumed limit, bill calculation).

IV. IMPLEMENTATION, TESTING, AND DEPLOYMENT DETAILS

A. Sensor Network

The hardware utilized to build an iTrack prototype is the open source monitoring product provided by openenergymonitor.com (Figure 9). This is a relatively low-cost system itself consuming very low power.

Fig. 9. Hardware Architecture of the iTrack Prototype

The EmonTx (wireless sensor nodes) and Raspberry Pi (gateway) are the two main hardware components of iTrack system.

The EmonTx is designed to monitor AC electrical power on up to four separate house circuits through non-invasive clip to measure current and voltage (Figure 10). The device uses low power wireless energy monitoring node for monitoring voltage signal for full real power data; this data is sensed every 10 seconds. The varieties of information that can be produced by EmonTx V3 are Real Power, Apparent Power, Power Factor, Root Mean Square Voltage, and current [9].
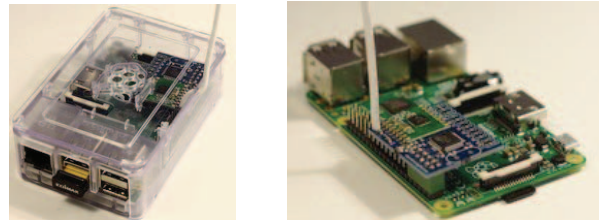

Fig. 10. EmonTx; Power Monitor

Fig. 11. Raspberry Pi; EmonBase

In Figure 11, we can see the Raspberry Pi (RPi) which is "credit-card sized Linux computer developed by the Raspberry Pi Foundation. The device has many applications both in the developed and the developing world" [10].

B. Data Saving

The Raspberry Pi is used as a base-station to log data generated from EmonTx locally. It is equipped with RFM12Pi wireless adaptor board to forward the data to a remote unit over the Internet [11]. In the remote unit, data are saved on a MySQL database for further visualization, post-processing, and alerting. The iTrack software also ensure synchronization between the utility database and the iTrack database, through a background process that is run in the server automatically. Configuring the processes to run is done using Cron jobs.

C. Visualization, and Alerting

As mentioned before, iTrack website is developed using MVC architecture. So, it has three kinds of files; the view files that contain all the interfaces' code (HTML, CSS, JavaScript, jQuery); the controllers file which contains all the PHP code that connect the interfaces with the Model classes; the Model files which contain classes to hold the information coming from the database. The technological choice was based on rapidity, interoperability and ergonomic criteria. In Fig.12, the page displays the electricity consumption of the user, with the real-time bill calculated, and the percentage with respect set to total consumption. A process running daily compare the total energy consumption with the set limit, if any, and send an alert message if the consumption reached 75% of the limit.
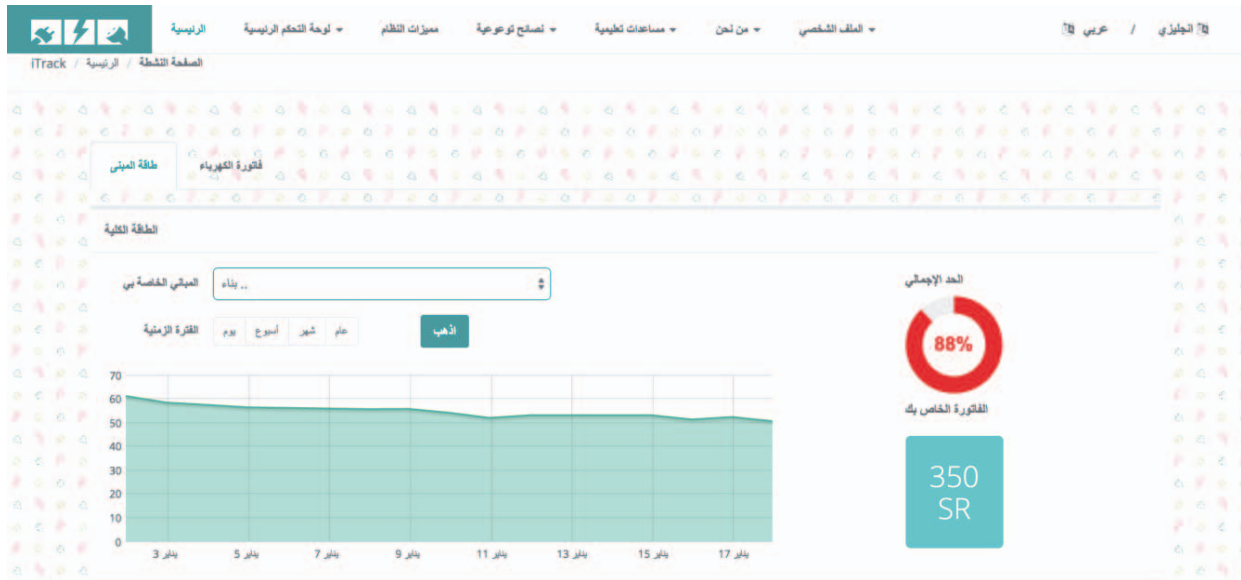
Fig. 12. Building Power (General Power) Interface

D. Security

Many security mechanism have been used to increase the security of the iTrack website. The md5 technique is used to encrypt the user password. The captcha code method is used to insure that the user of the system is a human not a machine. Also, when the user sign up, add dependent or change his/her email, he/she will receive a verification message to insure that the user provided the correct email address, if the user try to hack our system using this link the system will detect that. The iTrack system is thus robust against hackers that would try to get the privileges of other user.

V. CONCLUSION

This study outlined the design, development, and implementation phases of a residential energy monitoring system that has been tailored to meet local needs, that is to say a non-intrusive system with a user friendly interface available both in English and Arabic endowed with an alert system, and also providing energy saving and awareness tips. The iTrack system has been fully deployed, and is currently hosted on a VPS managed through a CPanel listen. The prototype hardware is also currently used on-campus to monitor electricity consumption of appliances in faculty office area.

Future enhancement are planned through implementation of new useful functionalities, such as the incorporation of fault detection techniques utilizing already available sensor measurements, for a system robust to sensor failures, or an automated setting of the sensors by providing a visual blueprint of the house instead of manually inserting the building information.

REFERENCES

[1] Y. Alyousef, and M. Abu-ebid, "Energy Efficiency Initiatives for Saudi Arabia on Supply and Demand Sides, Energy Efficiency - A Bridge to Low Carbon Economy," InTech, 2012.

[2] Saudi Arabia: Enerdata and the Economist Intelligence Unit. (2011). Saudi Arabia Energy efficiency report

[3] Hertog, Steffen, Luciana, Giacomo. "Energy and Sustainability Policies in the GCC," in Proc. Kuwait Programme on Development, Governance and Globalisation in the Gulf States, 2009.

[4] Dietz, Thomas, et al. "Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions." Proceedings of the National Academy of Sciences 106.44 (2009): 18452-18456.

[5] C. Fischer, "Feedback on household electricity consumption: a tool for saving energy?," Energy Efficiency, Vol. 1, No. 1, pp. 79–104, 2008.

[6] Utility Rates API | api.data.gov . 2014.

[7] Microsoft Developer Network. Chapter 3: Architectural Patterns and Styles.

[8] TechTarget SearchNetworking. client/server (client/server model, client/server architecture).

[9] (2015). *Main Page*. Available: http://wiki.openenergymonitor.org/index.php/Main_Page.

[10] (2015). *RPi Hub*. Available: http://elinux.org/RPi_Hub.

[11] OpenEnergyMonitor. Getting started. Available: http://openenergymonitor.org/emon/guide.