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# Home Energy Management through Historical and Real Time Data Visualization in A web User Interface Based Dashboard

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***Abstract— Nowadays the need for home energy use is increasing in almost all developing countries, the mechanisms set to deal with this issue is to raise installed capacities, however this has negative effects on environment and the wild lives in general. For instance the burning of fossil fuel for domestic and commercial energy production has contributed too much CO2 emissions that results to global warming. Therefore, controlling home energy consumption would exist as a stepping stone to handle the problems mentioned above. Not only these but also the problem of shoot-up in electricity bills in our can be resolved. In this research database/tables were designed for the storage of raw power data, intermediate statistical tables were designed to demonstrate the energy data that end users are truly concerned, A user interface based dashboard for home energy management was developed, historical home energy consumption data can be visualized via the dashboard and basing on this end users can alter their energy consumption behaviours. Real time consumption is simulated using high chart gauges. End users are facilitated to register their information together with their devices used for raw power data collection- PC MAC ADDRESS in this case. Energy consumption data over a couple of past months are compared and variations in consumption patterns assist home owners to draw out conclusions on energy use especially reflecting on the peak hours.***

***Keywords— HEMS, Smart Home, Historical and Real Time Data, Web UI Dashboard***

## I. INTRODUCTION

The process of monitoring, controlling, and conserving energy in our homes is generally known as Home Energy Management System(HEMS), however it can also mean any device or a system in domestic premises that is employed to control energy consumption, the system involves identifying energy saving opportunities and providing required information to home owners that would influence their energy saving behaviours. In [1], authors indicate that smart energy management is not only on how it is supplied but also on how it is used. Presently , many countries encounter an imbalance between electricity production and demand. The impact of this difference is a remarkable rise in electricity prices. Effective HEMS must be a continuous process, a sharp eye must be kept on energy consumption data at some fixed time intervals as unwatched HEMS may become less efficient as time elapses[1,2]. This prevents the long existence of a simple fault that may leave a huge energy electricity bill if not fixed. In short, a HEMS includes any product or service that monitors, controls, or analyses energy in the home. This may include utility demand response programs , home automation services, personal energy management, consumed data analysis and visualization , auditing, and related security services.

Different research works are being carried out on HEMS. Various technologies have been employed to design and construct HEMS architectures , including sensor networks[3]. However, the process of storage and demonstration of consumed energy data needs to be improved and extended to the end users. Basically information on home energy consumption is highly required to all home members so that they are all aware of their consumption patterns. Therefore research activities must be performed on HEMS especially basing on the historical consumed energy data visualization. In fact, if home owners would manage to store and visualize their energy consumption data, can be the foundation of decreasing it and reduce electricity expenses as well.

### Statement of the problem

Home energy management is a challenge to many families. It is difficult for energy consumers to know how much they have utilized over a period of time or even track their domestic live power readings. With this research work we are introducing a HEMS that will enable historical energy data and real-time power data visualization. Energy usage patterns for some specific periods, for example weekly or monthly energy consumption will stimulate homeowners' energy saving attitudes and help them to save their expenditures on electricity.

### Aim and Objectives

Our work aims to carry out a research work on Home Energy Managements System so that consumed energy data in homes can be collected and stored; this would allow visualization of this data via a web user interface based dashboard for further analysis and decision taking on energy use. The objectives to achieve this include:

- Having Sufficient knowledge on the Home Energy Management Systems by reviewing various related research works
- Designing database/tables for the storage of homes' energy data and intermediate statistical tables to enable historical data demonstrations.
- Developing an interactive web based dashboard that will be used for historical energy data comparison, visualization plus real time data simulation.

**Scope**

This research focused on developing a domestic energy management system that will facilitate historical energy Data Storage and demonstration, plus real time power data visualization through a Web UI Based Dashboard.

**Methodology Used**

The methodology that has been utilized for this research includes literature survey that allowed us to point out potential challenges in HEMS, and provided us with clear direction of research where much emphasis should be put. Not only this but also involved HEMS design, it included the conceptual model of HEMS that comprises of database/tables that are used to store raw power data. The web UI based dashboard was designed via which consumed energy data should be visualized. The methodology involves implementation of all designed databases tables and programming the dashboard. Finally an evaluation was conducted to assess the functionality of the developed HEMS dashboard along with the relevant database/tables.

## II. REVIEWING HOME ENERGY MANAGEMENT SYSTEMS

It is believed that initially, Energy Management Systems(EMS) activities were best on analogue meters but limited in scope and application in some functions, this was developed as early as 1970s, However, improvements on HEMS targeted Demand Side Management[4]. The technological advancement in the 1980s further changed the EMS, especially with the development of personal computers. Early advancement of EMS, were based on Proprietary hardware and operating systems, the most common manufacturers of early EMS include General Electric (then Harris Controls), Hitachi, Siemens and Toshiba, Later Software based system such as UNIX, LINUX and Windows-based systems added many possibilities to the EMS solutions in the early 2000s[4].EMS also has age-long application in the residential sector. However, energy management became a real concern especially with the multiple energy crises, increasing cost and with the idea of energy conservation in the 1970's [5] .Like any other EMS, home energy management systems have the end-goals as to conserve energy, reduce cost and improve comfort. End user awareness contributes a good % in Home Energy Savings [5, 6,7].

Today's world is experiencing a challenge in fighting against the green house gases emission which is the major cause of global warming. Researches show that carbon dioxide ($CO_2$) contributes 72% 0f the total emissions of the greenhouse gases [8]. The generation of energy required for domestic, commercial and industrial sometimes requires the burning of fossil fuel and this is the main source of $CO_2$ emissions. For example in United Kingdom domestic energy consumption contributes to 27% of the overall $CO_2$ emissions [8], this explains why reducing energy wastage in our homes (HEMS) is a big environmental bonus as it decreases carbon emissions. This is facilitated by employing a well configured home area networks (HAN). It is taken as a network of energy management devices, this includes digital consumer electronics, signal-enabled appliances, and applications within a home environment that is on the side of the electric meter.

**Home Energy Management System Hardware topology**

As represented in the illustration below, the initial part of HEMS topology is made up of multiple sensors, the purpose of sensors is to collect the power consumption data from the plugged-in home appliances, but at the same time may be used in switching the power supply of the plugged-in appliances. With the actuator it is possible to request and collect data from the power outlet sensors [10]. In a typical HEMS hardware arrangement a PC is required to transmit data between the actuator and the database server that hosts raw power data database and control database (CDB). CDB controls the power socket sensors triggers switching of power supply.

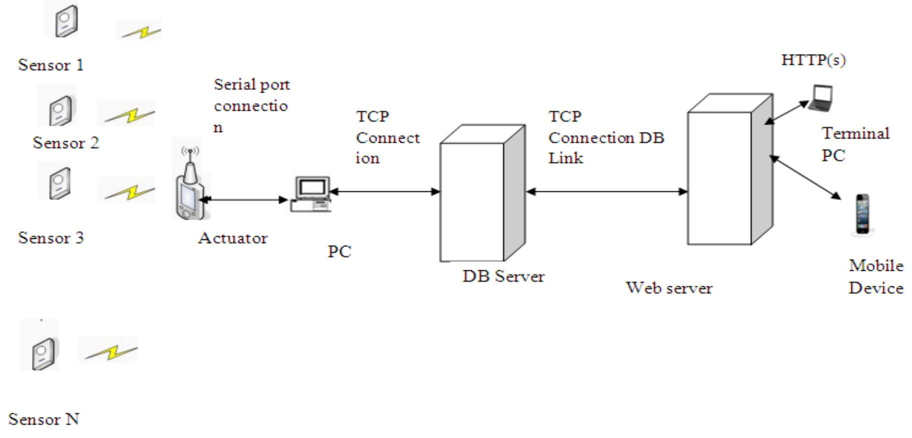


Fig. 1 HEMS, hardware topology adopted in [10]

**Home Energy Management System software application**

This is another important component required in HEMS arrangement and this is used to host web application for an overview of the data stored in power data. Terminal nodes are the browsing tools, these may be PCs or smart phones used to access the web application [10].

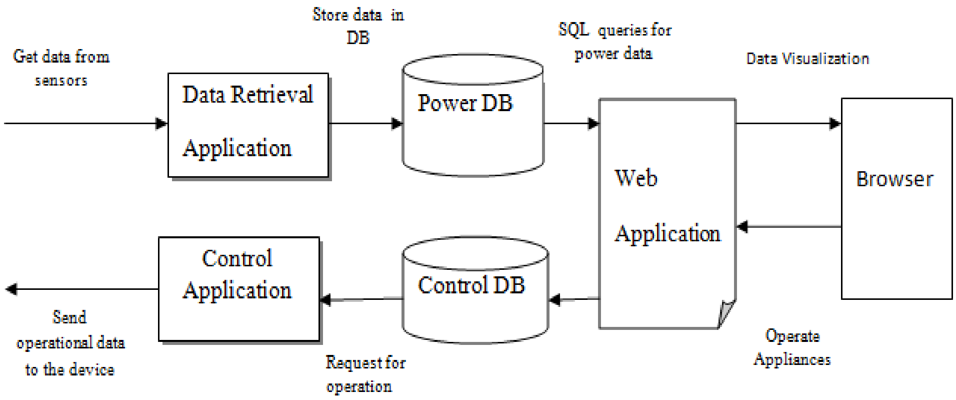


Fig. 2 HEMS , software application adopted in [10]

HEMS provide ways of electricity meter readings, obtained readings should be used to generate pattern analysis and consumption forecasts, HEMS have reasonable contributions in the Traditional power systems . The absence of robust HEMS in traditional grids has counted for high energy loss. As such the imbalance between energy demand and supply is obtaining great concern. Utilities and governments in developing countries are in a transition from ancient grid to the smart grid. The advancement in ICT is being utilized as a tool to boost automation and monitoring procedures .The development in metering infrastructure has helped measurement of detailed, time-based information and periodic collection of data and this is easily transmitted to the required destinations .

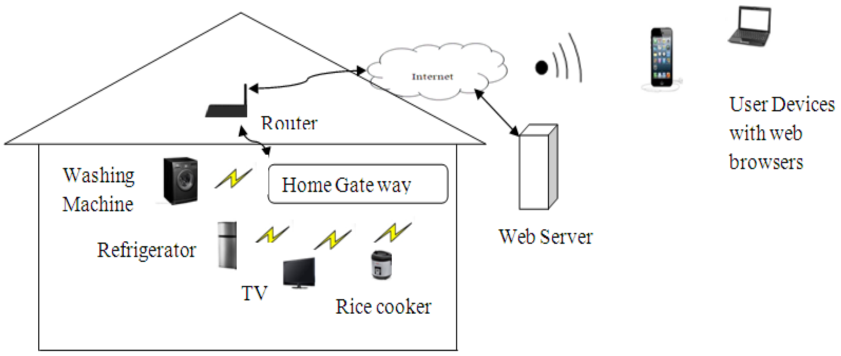


Fig. 3 HEMS with home gateway

**The role of a gateway in Home Energy Management System with**

In every effective HEMS a Gateway is needed as a solution intended to provide an interface to both infotainment and electrical appliances in our homes to the outside world. The home gateway performs the inter-operation among the heterogeneous devices inside the home; it performs device discovery, device identification and others. For all these to be possible smart meters are required and these act as the backbone of Home Automation using Home Area Network (HAN) and can serve as a viewer and controller of home energy consumption.

**Internet of Things (IoT) in Smart Homes**

Internet of Things is a novel communication and Network model that links objects to network and share information, apart from information conveying, IoT assists in analysing the collected data. In Smart Homes, it helps in consumption forecasting and prediction. The capability to predict future power consumption in our homes is a crucial component of several other applications that look ways out to save or enhance management of energy resources.

**Challenges to Home Energy Management Implementation**

Regardless of the advancement in technological infrastructure, there are still several challenges that slows HEMS implementations and it is worthwhile cardinal to mention that these challenges have always been a cause to the wide spread of Home Energy Management System. Among other challenges they include:

*i. HEMS costs:* Both hardware purchasing and skills required for installation lead to the high price of a well functioning HEMS. End users remain un interested to invest in home projects that yields less profit in comparison to the their investment. However HEMS benefits are said to be indirect and in the long-term[11].

*ii. No fit for all HEMS:* Home owners are obviously not HEMS implementers and have low awareness as far as HEMS operations are concerned. There are a lot of HEMS at the market and there is none that is a fit for all solution to home energy management *iii. HEMS & Smart grid integration:* HEMS is not a standalone System , it should be integrated with smart grid. Researchers have demonstrated inefficient of individual standalone HEMS and explains better optimization and utilization of resources by aggregating both HEMS & smart grid. However, integrating many HEMS into the entire smart grid system remains a big challenge.

*iv. ICT selection & HEMS intelligence:* The implementation of intelligent HEMS requires ICT as an enabler , however some end users are concerned with potential hazards as a result of wireless signals in their premises during HEMS implementations. Intelligent HEMS should employ smart end users measures based on hardware and software arrangements. Furthermore, producing a system that handles customers problems becomes a difficult challenge as they do not have sufficient knowledge about HEMS. [11].

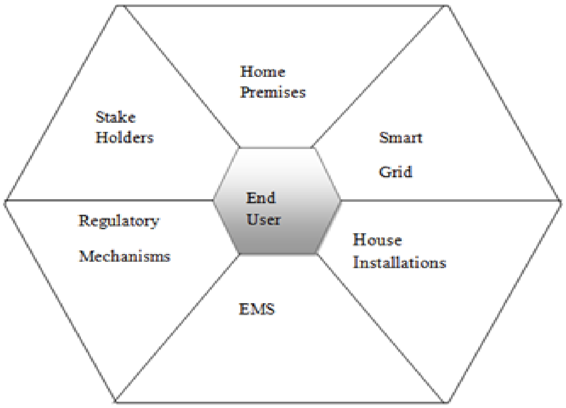


Fig. 3 Advanced Framework for EMS Adopted in [11]

The figure above represents the framework for advanced HEMS. It includes residential premises, the linkup of HEMS to the power utilities is a crucial practice as it boosts demand response operations. the house installation is also included in the framework. This explains if there is enabling technology. The presence of smart devices(Eg. Smart meters, Sensors, and smart residential appliances ) is introduced in this sector of the framework.

## III. HOME ENERGY MANAGEMENT SYSTEM, HARDWARE AND SOFTWARE SELECTION

The previous part reviews distinguished HEMS architectures, required components for a comprehensive HEMS system, various HEMS descriptions have been presented, in this part we highlight both hardware and software used to implement our HEMS .During the development of the HEMS in this research MySQL database management system was chosen due to its popular features, MySQL is the database system that is fully used on the web applications and runs on a server. This database system is also adopted because it is easy to use, very fast and reliable. MyEclipse Integrated development environment (IDE) was used as well, servlets were used to process data, in my study servlets are used also to display energy data in the high charts plugins used for energy consumption visualizations. Web Server: The developed HEMS required a web server, for this study Apache TomCat web server was used, it is software implementation of java servlets and Java Server Pages technologies. The application developed is on domestic energy monitoring and demonstration. The hardware included a clamp-on current transformer(CT) unit, a stand-alone display, a serial cable, and a web server. Power consumption is obtained using the CT unit, and transmitted to the display. The serial cable is then used to get the data from the display to our laptops (in this case it is the gateway and the web server at the same time). The application implemented collect readings from the CT unit, and show them via a web based dashboard. Furthermore, research work focuses at data visualization . The transmitter and the sensor jaw are integral to stand alone display functioning. The Energy Transmitter utilized has the following specifications: Product Size(12cm*7xcm*3 cm), with long lifetime-replaceable battery. It can sense one, two and three phases. Operates at a frequency of 50 Hz and associated with sensor current sensitivity worth 50mA and has a maximum rated Current of 100A. The wireless Transmission mode is 433MHz SRD band with Digital Modulation. The installation of this device is very simple as it does not require any electrical wiring works. Basic electrical knowledge is required to set up this equipment. For instance plugging the display's charger, and clamping the ct on the cable through which power should be measured ,no pre-requisites required to use the transmitter .

**System functions and features**

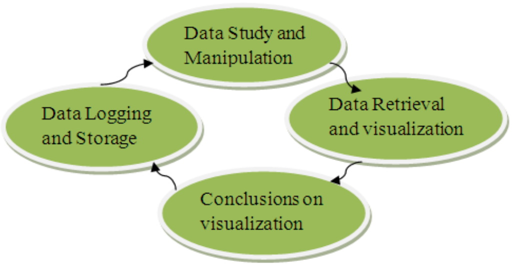


Fig. 4 HEMS Functions

**Data Logging and Storage**

Power readings were measured and transmitted by use of clamp on current transformers, this device is able to sense current in a current carrying wire on which it is clamped on and displays power in watts on a separate stand alone display. It therefore helps in the process of data measurement and collection, Various Technologies were considered to develop the web application in this paper, including java and XML[12]. Storage is enabled by the use of a MySQL database management system. All power readings data were collected and stored in a single main database table. In this scenario, consumed kilowatt-hour (KW) is given by this expression:

$$1\ \mathrm{Kwh} = \{\sum_{i=1}^{i=3600} \mathrm{Pi(t)}\}/1000$$

Where Pi(t) is power consumption at instant i and t= Time in seconds, this implies the amount of power consumption with in 1 hour.

Object Browser | Data Browser | SQL Editor

| mac | sample_time | ch1_watt |
|---|---|---|
| 0004A3000000 | 2010-05-30 15:53:57 | 530 |
| 0004A3000000 | 2010-05-30 15:54:02 | 620 |
| 0004A3000000 | 2010-05-30 15:54:06 | 690 |
| 0004A3000000 | 2010-05-30 15:54:10 | 760 |
| 0004A3000000 | 2010-05-30 15:54:12 | 790 |
| 0004A3000000 | 2010-05-30 15:54:14 | 820 |
| 0004A3000000 | 2010-05-30 15:54:16 | 850 |
| 0004A3000000 | 2010-05-30 15:54:18 | 880 |
| 0004A3000000 | 2010-05-30 15:54:20 | 910 |
| 0004A3000000 | 2010-05-30 15:54:22 | 940 |
| 0004A3000000 | 2010-05-30 15:54:23 | 950 |
| 0004A3000000 | 2010-05-30 15:54:26 | 1000 |
| 0004A3000000 | 2010-05-30 15:54:27 | 1010 |
| 0004A3000000 | 2010-05-30 15:54:30 | 1040 |
| 0004A3000000 | 2010-05-30 15:54:35 | 1130 |
| 0004A3000000 | 2010-05-30 15:54:39 | 1200 |
| 0004A3000000 | 2010-05-30 15:54:42 | 1250 |
| 0004A3000000 | 2010-05-30 15:54:48 | 1360 |
| 0004A3000000 | 2010-05-30 15:54:52 | 1430 |
| 0004A3000000 | 2010-05-30 15:54:55 | 1480 |
| 0004A3000000 | 2010-05-30 15:55:01 | 1590 |
| 0004A3000000 | 2010-05-30 15:55:03 | 1620 |
| 0004A3000000 | 2010-05-30 15:55:07 | 1630 |
| 0004A3000000 | 2010-05-30 15:55:09 | 1660 |
| 0004A3000000 | 2010-05-30 15:55:11 | 1690 |
| 0004A3000000 | 2010-05-30 15:55:13 | 1720 |
| 0004A3000000 | 2010-05-30 15:55:15 | 1750 |
| 0004A3000000 | 2010-05-30 15:55:16 | 1760 |
| 0004A3000000 | 2010-05-30 15:55:19 | 1810 |
| 0004A3000000 | 2010-05-30 15:55:20 | 1820 |
| 0004A3000000 | 2010-05-30 15:55:23 | 1870 |

Fig. 5 collected & Stored Raw power data

| mac | hours | AvgEnergy |
|---|---|---|
| 001F1F217B04 | 00 | 0.309 |
| 001F1F217B04 | 01 | 0.297 |
| 001F1F217B04 | 02 | 0.298 |
| 001F1F217B04 | 03 | 0.273 |
| 001F1F217B04 | 04 | 0.261 |
| 001F1F217B04 | 05 | 0.262 |
| 001F1F217B04 | 06 | 0.261 |
| 001F1F217B04 | 07 | 0.268 |
| 001F1F217B04 | 08 | 0.544 |
| 001F1F217B04 | 09 | 0.658 |
| 001F1F217B04 | 10 | 0.432 |
| 001F1F217B04 | 11 | 0.401 |
| 001F1F217B04 | 12 | 0.366 |
| 001F1F217B04 | 13 | 0.371 |
| 001F1F217B04 | 14 | 0.576 |
| 001F1F217B04 | 15 | 0.610 |
| 001F1F217B04 | 16 | 0.436 |
| 001F1F217B04 | 17 | 0.787 |
| 001F1F217B04 | 18 | 0.711 |
| 001F1F217B04 | 19 | 0.727 |
| 001F1F217B04 | 20 | 0.864 |
| 001F1F217B04 | 21 | 0.852 |
| 001F1F217B04 | 22 | 0.776 |
| 001F1F217B04 | 23 | 0.450 |

Fig. 6 Computed Energy Data

The table designed consists of three fields, **mac**(a unique physical address of the home PC) , **sample_time**( represents the instant during which each data sample was collected ) and finally**ch1_watt (** which stands for the amount of power reading at every sample time timestamp), as demonstrated in the screenshots above, the firs table was designed to accomplish the task of raw power data storage, to its right indicated an intermediate statistical table that hosts consumed energy data that end users are truly concerned.

**Raw Power Table**

| Field | Type | Null |
|---|---|---|
| mac | <MEMO> | NO |
| Sample_time | <MEMO> | YES |
| Ch1_watt | <MEMO> | YES |

**Consumed Energy Table**

| Field | Type | Null |
|---|---|---|
| mac | <MEMO> | NO |
| hours | <MEMO> | YES |
| AvgEnergy | <MEMO> | YES |

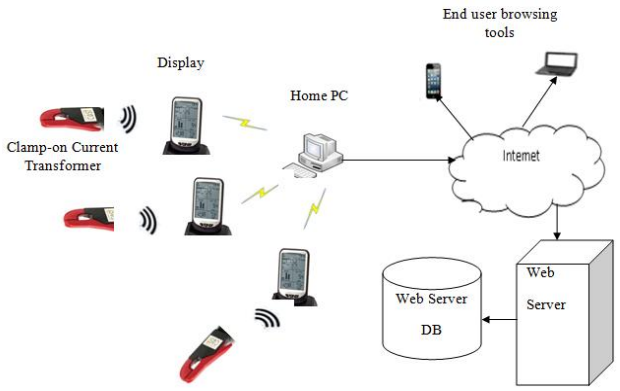


Fig. 7 Raw power data collection and storage

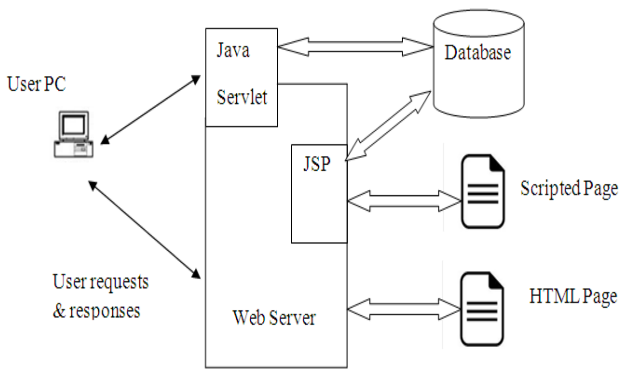


Fig. 8 Data Retrieval and display

Data retrieval in this system is based on java server page requests; SQL queries are utilized to get data from the database and via servlets is displayed in high chart plug-ins for historical and real time data visualization [13].

## IV. USER INTERFACE DASHBOARD IMPLEMENTATION

In previous section, we explain how raw power data were collected, stored and manipulated. Raw power is stored in a web server database, this enabled us to implement a web based and database driven HEMS. With MyEclipse we accomplished all the development works, Ajax and XML are employed to help us submit and retrieve data from severer without tampering the display behaviour of the dashboard. The developed HEMS validates users vai a register/login process. Users are requested to register their information and the identifications of the device used to collect raw power data which would uniquely identify the user.


Fig. 9 HEMS user Registration form

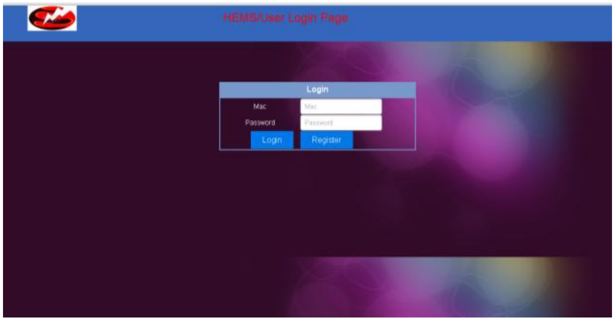


Fig. 10 HEMS user login panel

A registered HEMS user should login to track his consumtption details over a numbers of months and realtime data visualization. As presented in the previous section , each user in this case the home owner is uniquely identified by the physical address of the device eployed to collect raw power data and password. In this scenario every user can login and access the UI dashboard from where both hsitorical and live consumtion visualization is enabled. As stated in the previous sections historical data trends directly initiates consumption forecasts in the endusers . The implemention of both historical energy data and live power visualizations is enabled by various highchart plug-ins, this is mainly a web service[14]. Highchart library is written in pure javaScript. This provides a convinient way of adding more interractive charts in the web dashboard [15,16]. Highcharts support a number of visualization modes, but as observed in our implementation, only line charts and guages were utilized.

### Historical energy data retrieval and demonstration

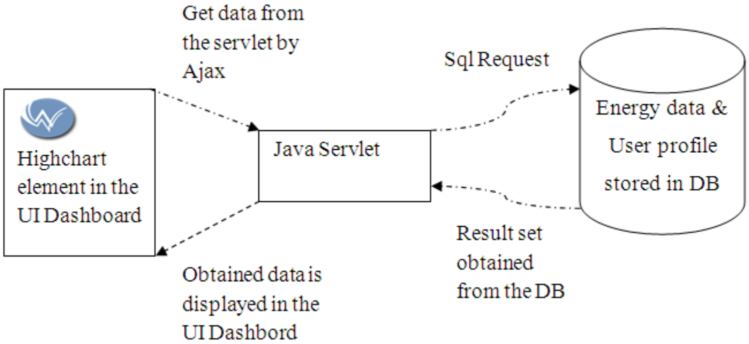


Fig. 11 Historical energy data retrieval and demonstration

The result set is a collection of data representing a database result set, it is actually generated by executing a statement that qyeries the database [17].

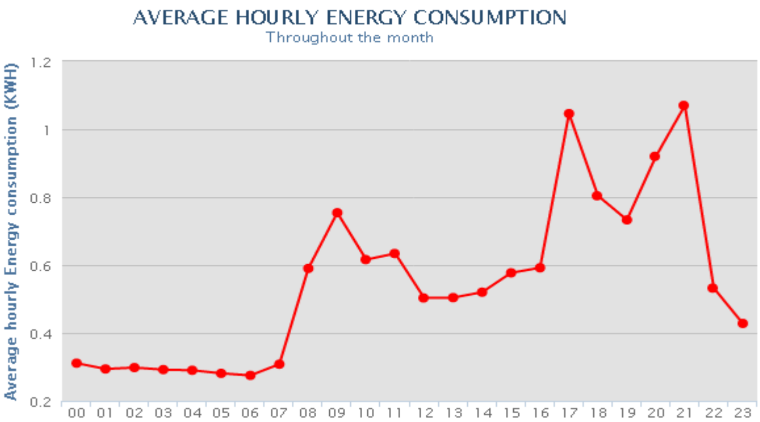


Fig.12 Historical energy data visualization(i)

 

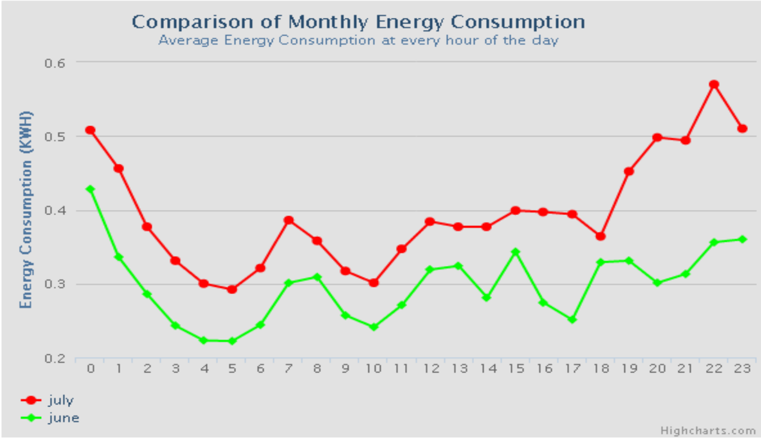


Fig. 13 Historical energy data visualization (ii)

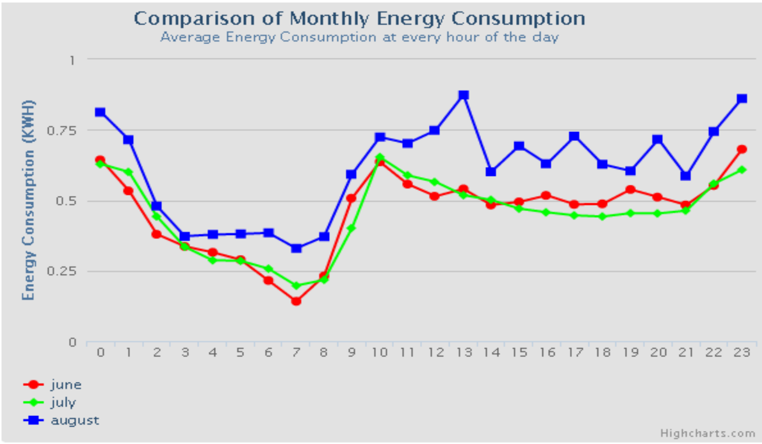


Fig. 14 Historical energy data visualization (iii)

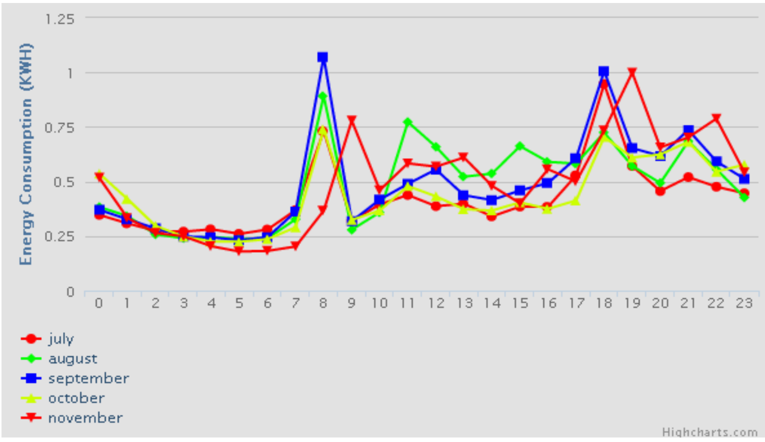


Fig. 15 Historical energy data visualization (iv)

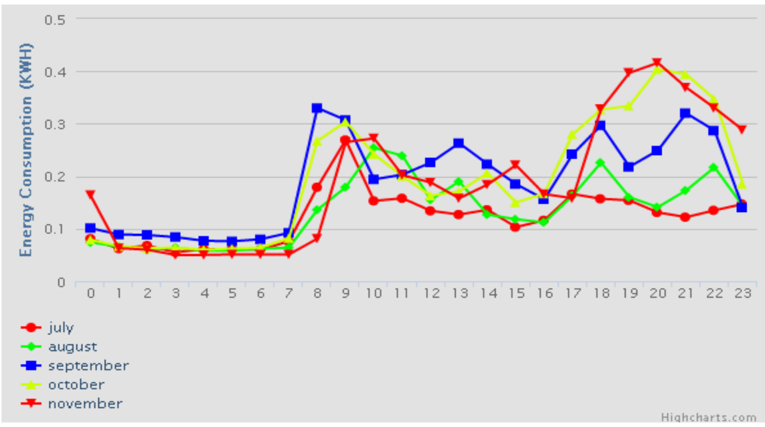


Fig. 16 Historical energy data visualization(v)

 

The line charts show consumption of energy in the indicated months for different homes, note that the graphs represent the average hourly consumption throughout the month. From such trends , decisions could be taken basing on peak hours . The users decide to change their energy consumption behaviors, it is therefore undoubtable that historical energy data comparisons contribute a lot to the projection of energy usage in future especially in consumption reductions[18]. The above line charts demonstrate energy consumption comparisons for different homes and in different months. Forexample , consumption in june and july would help home owners to determine what it should be in the left moths of the year.

**Real time data simulation**

Real-time data is often referred to as RTD, in this scenario is also called live data. Historical energy usage data has been demonstrated above in line charts. The function of Real Time Data demonstration is to allow end users visualize instant overall power consumption in monitored homes [18,19]. The overall live consumption is visualized using a meter that resembles a vehicle's speedometer . This improves the behaviour of recognizing and visualizing the status of live power consumption in homes.


Fig. 14 Real Time Power Data display

If we partition every single day into T time slots, represented as $T=\{t_1, t_2, t_3, \ldots t_n\}$, Assuming a set of appliances in home denoted by $A=\{A_1, A_2, A_3 \ldots, A_n\}$, The total power consumption $P_t$ at time t, where $t \in T$ is given as

$$Pt = \sum_{i=1}^{n} PAi(t)$$

Where Lt is the total load at time t

$L_{Ai}(t)$ denotes every individual Appliance load at time t

The gauge implemented is a high chart java script plug-in which is viewed in the application web based dashboard page via different browsers. Highchart libraries provided us capabilities to implement a gauge with coloured regions. In this Scenario, red part of the gauge implies high power consumption, this would result during peak hours of the day. In other words when all house appliances are in operation.

## V. CONCLUSION

In this work, a HEMS was designed and implemented, it is meant to achieve all the objectives stated in section I, relevant literatures were reviewed and sufficient knowledge about HEMS was achieved. To enable raw power data storage and demonstration database-tables were designed, in addition to this a well organized web based user interface based dashboard was implemented via which both historical and live data can be visualized. Monthly consumption comparisons would instil energy saving attitudes in the end users minds. In summary, this work is regard to home energy management systems can be thought to be made up of two major parts. Initially raw power data were collected and stored, hourly energy consumptions were calculated to recognize peak hours. Secondly, the development of HEMS user interface based dashboard through which end users may use for historical and live data visualization.

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