ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 1, Issue 9, November 2012

Improving energy usage efficiency in web enabled smart buildings

Szalontai Levente

Abstract— **Today, smart building systems are extending beyond a usual phone or computer network, including any imaginable electronics devices forming interconnected networks of physical objects. Various buildings don't have any more the status of a simple residential destination; they offer besides building's consumption optimization a high level of security and comfort. Anyway residential sector is one of the major consumers of energy in both the US and EU due to many different factors. There's a waste of energy when heating/cooling systems are working in unoccupied places; when overheating and overcooling various building places. To archive an efficient reduction of energy consumption, smart building systems have to be used to control, end user's behavior and in the same time to offer valuable information about specific device's energy consumptions. A developed prototype system will be presented in this paper, and experimental results will be provided to verify the correctness of the proposed system.**

Index Terms—**energy usage monitoring, IoT, smart buildings, smart lightning.**

I. Introduction

Residential electricity consumption represents the third of the total electricity consumption [1, 2, 3]. To decrease energy consumption, there are two different directions. T are passive solutions referring to simple robust systems to allow low energy consumptions by integrating available efficient solutions (like insulation, energy recovering, etc.). There are intelligent solutions that require a platform to integrate high-tech solution, to use building automation for integrating various sub-systems to automatically adapt to changing needs and conditions that are attained through advanced sensing and monitoring technologies.

By using building automation is expected the energy reduction to be in the range of 5% to 10-12% and as much as 80% according to some optimistic forecasts. Besides the comfort and security that a building can provide another issue is related to efficient energy management that has to be supported by smart monitoring and control devices spread all over the buildings.

Consumer behavior related to energy consumption is very important but as this parameter can't be controlled technological solutions like smart building automation seems to be a better way to archive desired target instead of those that aim is changing people's energy-saving behavior. Anyway, there are people who could and would like to change their behavior but the biggest problem is that they don't know how much energy they are consuming and what appliances do consume the most energy. The single feedback that an end user receives is the billing information from the energy distribution company. There are various energy measurement systems that appeared in the market like Kill A Watt [4] that can show electricity consumption and other informations, generally they can't give an overall picture and are not communication enabled, not being able to integrate them into a smart building system.

This paper describes a smart building system's energy measurement devices and smart lightning system, both having the objective to reduce energy consumption. An out-of-the-box type solution will be present.

The rest of the paper is organized as follows. Section II introduces some solutions regarding smart building systems and how various devices are connected between them. In section III are presented two wireless energy monitoring devices respectively a wireless communication enabled smart bulb. In section IV are presented some informations about the smart grid and how could be the energy monitoring device integrated into the grid. In section V are described the embedded device software features and the graphical interface. Section VI contains relevant results based on the presented system. Finally, in section VII are presented the most important conclusions and future development directions.

II. Smart building system

Smart building systems as a technical solution, to have any effect regarding energy savings should be extremely widespread but there are numerous challenges in deploying these systems in end users homes like:

- interoperability: lack of interoperability between various communication technologies;
- wireless node's energy consumption: that is influencing the used protocol due to battery-powered devices that are supposed to work for a long interval of time between battery changes;
- system upgrade: when new devices have to be added to existing system or old ones will have to be changed;
- scalability: where address space is limited by manufacturers due to memory constraints;
- cost: it's a very important limiting factor;
- user interface: there's no user friendly interface that could minimize the configuration effort of a smart building system network.

Based on ubiquitous computing technologies, there's

Manuscript received Oct 15, 2011.
Szalontai Levente, *Department of Basics of Electronics, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, Mobile no: +40-721374769.*

possible to capture multiple real-world informations that can

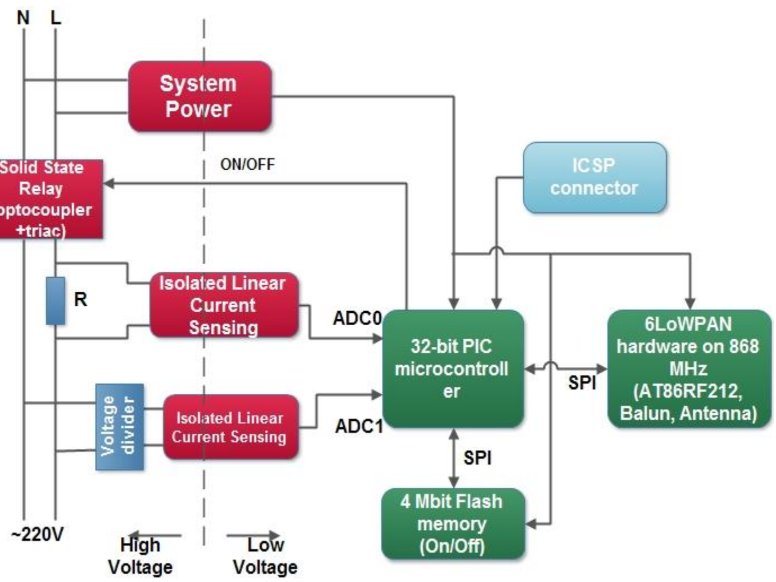

Fig. 2. Device level energy consumption measurement device block schematic

be visualized by using smart phones or any other display device.

The smart building system that contains the energy monitoring devices and the smart lightning system is presented in Fig. 1. It uses light bulbs to form a reliable wireless mesh network based on 6LoWPAN communication protocol. Using light bulbs as routers not only energy monitoring devices could be used in the smart building system but other household devices and through the gateway is possible to make very efficient physical features meshup that will be explained in section VI.

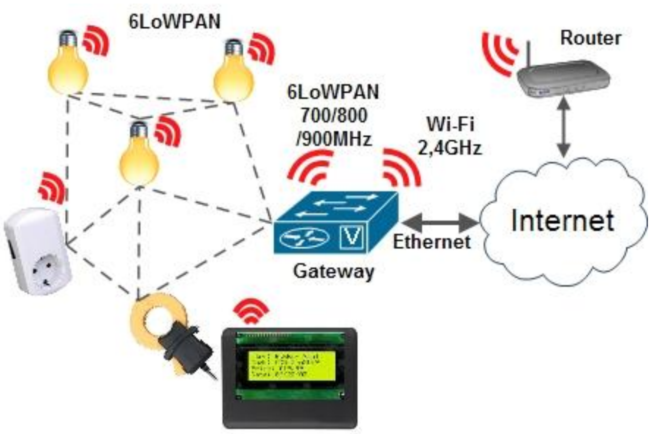

Fig. 1. Smart building system with energy monitoring and smart lightning system

There is multiple household energy monitoring solutions out on the market like Onzo [5], Wattson [6] or other solutions that are monitoring power consumption per circuit being mounted near the fuse box. There is also device level energy monitoring solutions like the mentioned Kill A Watt or Watts Up [7]. Anyway, these devices don't have a so flexible structure like the ones presented in this paper in the next section.

III. Energy consumption monitoring devices

Energy consumption can be measured in two different ways. The first one is by using device level energy monitoring devices like the prototype device presented in the A named PowerBoxL and household level monitoring devices like the one presented in part B.

A. *PowerBoxL*

This device can measure multiple parameters like real power consumption (W, KW), apparent power (VA), power factor, RMS voltage, RMS current, Frequency (Hz). To overcome the biggest problem in the approach of other smart electricity meters, instead of battery power for low voltage processing circuits, I use a powering module to get the necessary low level voltage.

Battery powered devices has several problems when batteries have to be changed, therefore, this solution is better even if the costs are higher. This device can measure energy consumption for various household devices or other devices that has a consumption of up to 3500 W. Device's block schematic is presented in Fig. 2.

Fig. 3. PowerBoxL with SFR card for 6LoWPAN communication

To be able to integrate this device into a smart building system it's enough to use a Smart RF (SRF) card that enables it to communicate on a low power wireless interface with other smart building systems. Anyway if there's no smart

ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 1, Issue 9, November 2012

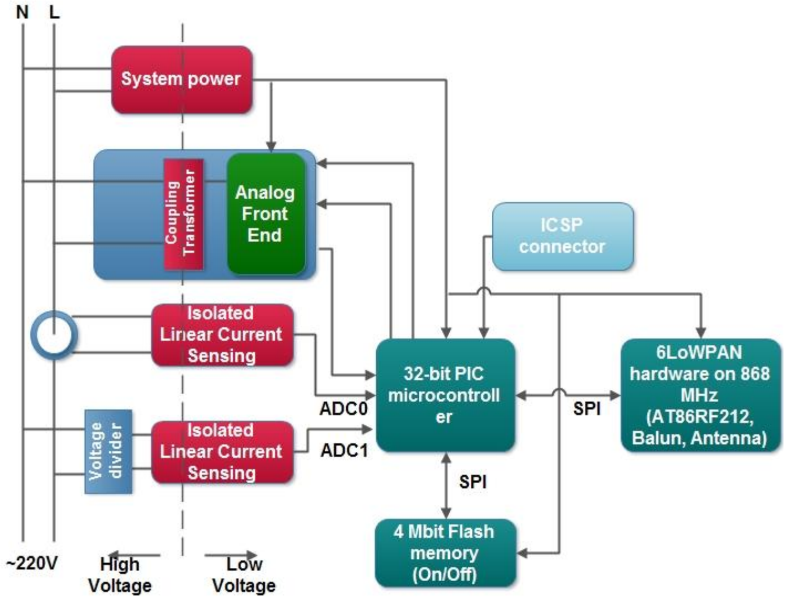

Fig. 4. Household level energy consumption measurement device block schematic

building system a Wi-Fi SRF card can be applied and start to communicate through an Ad-Hoc Wi-Fi interface with a smart phone or a PC that's Wi-Fi communication enabled. The device level energy monitoring systems is presented in Fig.3; it is connected between the power outlet and the power cord belonging to the device that will be monitored.

B. PowerBox

To be able to measure the overall power consumption than a household level energy monitoring device can be used. This one also has wireless connection that can be chosen by end users, that can be a low power communication interface, Bluetooth or even Wi-Fi. Besides the wireless communication interface this has a Power Line Communication (PLC) interface that helps to integrate this device into the smart grid.

This device can measure currents up to 150A that's more than enough for a smart building. It has a clamp to be able to attach it to the cable that has to be monitored for various current flows. There's a voltage divider that measures the voltage. Each connection to the low power electronic circuits are isolated for end user's safety.

Fig. 5. PowerBox with SFR card for 6LoWPAN communication

As long as this device is providing necessary data for energy distributing companies through its PLC interface and other informations to end users through a wireless interface, there's not necessary to have any visualizing device on it, anyway a detachable LCD display can be applied. It has a few user buttons to control its basic functions because the majority of its parameters are set through control devices.

The block schematic for the household level energy monitoring device is presented in Fig. 4, and the hardware in Fig. 5. Certain device's consumption measurements can be done also with this device, by turning off all the consumers and turning them on randomly measuring the total energy consumption, that represents device's energy use.

IV. Smart Grid

The PowerBox device has PLC communication capabilities. It was designed in such a way that it would be able to use the G3 PLC protocol that starts to be more popular, being evaluated in multiple geographical regions, with the precise objective of becoming a worldwide standard around the world.

As long as the device is using the FreeRTOS operating system to run multiple applications on various processing devices it will be a very easy job to add new features required by energy distributors to integrate it into company's smart grid network. The software updates for the required distributors network will be downloaded as easily as other software updates.

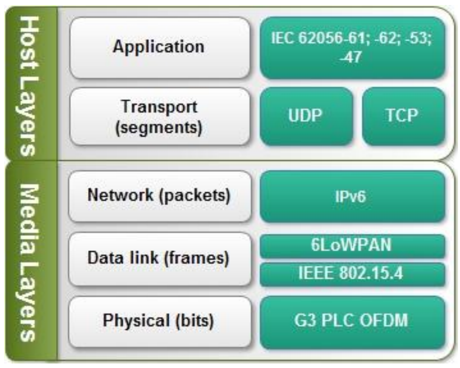

Fig. 6. ISO/OSI model for G3 protocol having IPv6, 802.15.4 and 6LoWPAN support layers

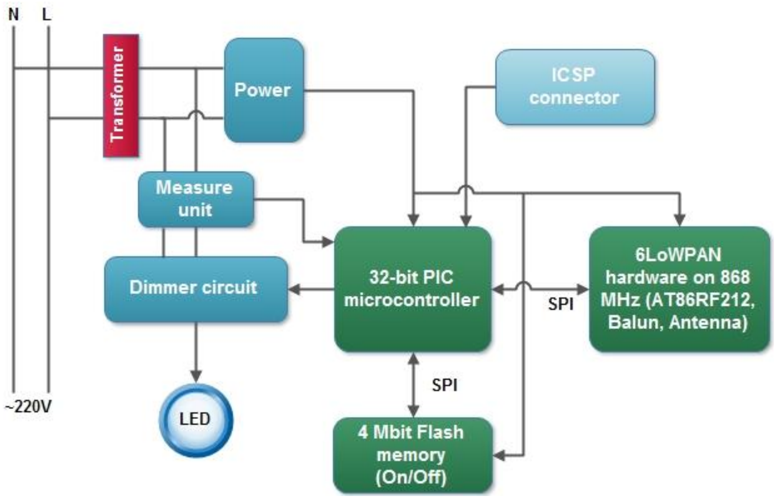

Fig. 7. LightBox block schematic

Even if the PLC communication doesn't work, for some reason, there's a second possibility to transfer required data based on 6LoWPAN protocol and the gateway device through a secured internet connection.

V. Smart Lightning Control

Another possibility to reduce a building's energy consumption could be archived by using smart lightning systems. To be able to efficiently use the 6LoWPAN network for data transfer, I use light bulbs as router devices, especially because they are powered all the time, therefore are not bound to batteries or energy harvesting solutions.

The LED light bulbs named LightBox – block schematic is presented in Fig. 7. The bulb has 6LoWPAN or any other 802.15.4 protocol communication capabilities. LightBox has dimming capabilities that help in setting the desired light intensity. The bulb measures its own power consumption therefore it's able to report that parameter. In the same time end users can apply various scenarios for each light bulb, each one being able to sense environment light level therefore being able to light up in various light conditions.

VI. Software Solutions for Monitoring

Each device from those presented in this paper benefit from a SRF card presented in Fig. 8. Each card is running on a 32 bit PIC microcontroller, providing the necessary speed to work as routers for the 6LoWPAN network.

From software point of view, each SRF card has a FreeRTOS operating system on it. Besides multiple tasks for measuring various analog signals, it has other tasks for 6LoWPAN communication.

The real time operating system has multiple advantages, especially those of allowing a more robust environment, large software loops being spread into chunks that are easier to manage; therefore, software reuse being the key issue, developers not having to restart software development for each new device.

When a new device has to be integrated into a smart building than with the help of SRF devices, there's possible to archive an easy and automatic process of updating software for the particular device based on informations from its XML description file that is located on a simple EEPROM memory that has been previously written by the manufacturer. The process of updating the software for a particular device is presented in Fig. 9.

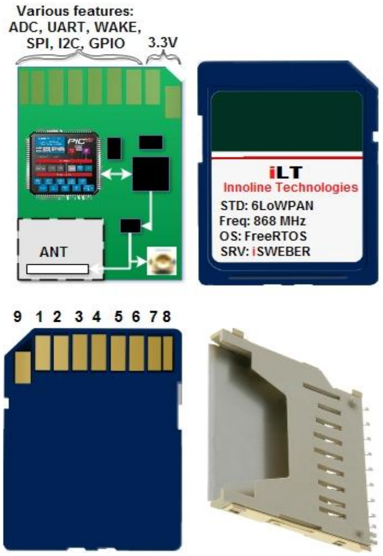

Fig. 8. Smart RF Card (SRF)

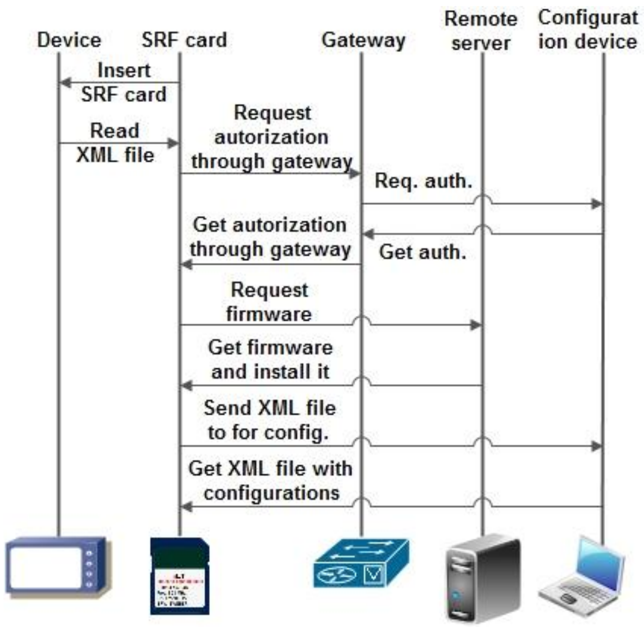

Fig. 9. New device configuration process

ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 1, Issue 9, November 2012

At the beginning, the XML file contains the most important informations related to a certain device like the manufacturer name, a unique ID and one of the most important informations, the web address where device’s firmware is located to be downloaded. Besides described informations, it contains the URI addresses of device’s objects that are defined as resources. Finally, after the installation is over the end user can meshup the existing device's features that will be explained in the following section by an example.

From end users visualizing point of view web technology based systems are easier to use because there’s no need to have a user interface for every single device, to be able to show data. A simple browser will be more than enough to get a device particular informations or to control various actuators.

VII. System Evaluation

The smart building system for evaluating device level and household level energy consumption is similar to the one presented in Fig. 1, with the only difference that it contains only 2 LightBox devices. Communication between devices is made on 868 MHz frequency using 6LoWPAN protocol. The 868 MHz interface was used instead of the 2.4 GHz to avoid the crowded frequency domain. Each device has a SRF card to be able to communicate through the wireless interface. As long as simple light bulbs don't have any relevant information except their own measured consumption in the evaluation process I will show some capture of the other two devices that were presented in this paper. Energy usage for a refrigerator is presented in Fig.10. The monitoring is made for 24 hours. The second device, the household level energy monitoring device results are presented in Fig. 11.

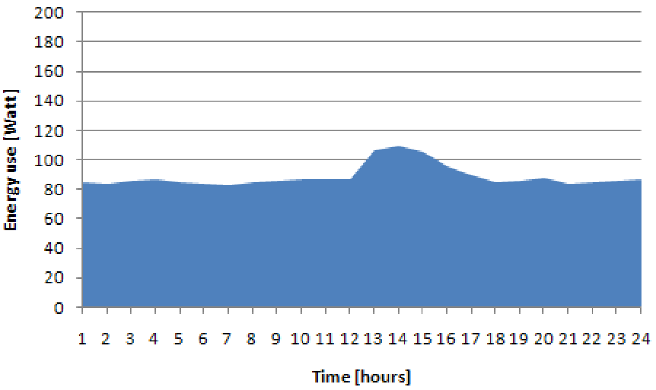

Fig. 10. Device level energy use monitoring for a refrigerator

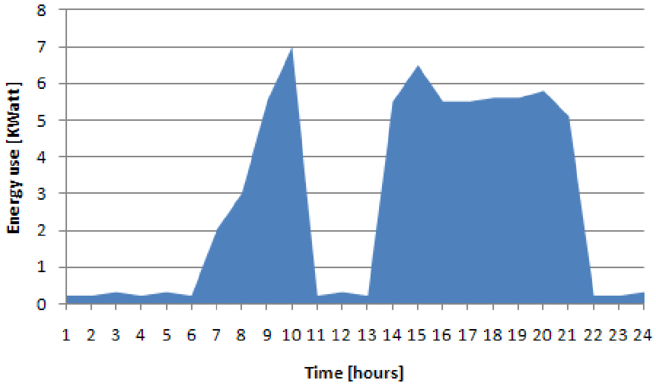

Fig. 11. Household level energy use monitoring

In Fig. 10 can be identified energy consumption, that rises when fresh food is added and door is left open by accident. In Fig. 11 is presented a household's energy usage profile, with maximum consumption in a day’s various time intervals.

Here I will explain why is so important the meshup process, that can bring many advantages for end users. If the energy distributor has different prices for the day and night than in the meshup process end user can specify for the washing machine when to start itself in order to use the cheapest energy. In the same time through the meshup process other conditions can be set like to give an alarm when the consumption is reaching a very high level in a certain day or working hours.

The meshup process is used for automatic notification of various processes or conditions in a certain network. Anyway besides this every single device can be checked for various parameters. By using the web interface package that contains all the graphics, read and visualizing sequences, it’s possible to access device level energy monitoring modules and turn it off if it was left running by mistake. Possibilities are endless based on described hardware and software solutions.

As mentioned before there’s possible to use various SRF cards like 802.15.4 (ZigBee, 6LoWPAN, WirelessHART and others), Wi-Fi, Bluetooth or any other future hardware that will support future protocols. By using SRF cards an entire smart building system can be reconfigured for a different protocol having the same devices without needing to change them.

VIII. Conclusion

There are multiple problems related to energy consumption that has to be solved. Anyway for an end user to be able to monitor its own energy usage some support has to be given; therefore, device level and household level monitoring devices has to be used to report effective consumption, in this way end user will be able to decide when and how much they should consume. As mentioned before, SRF cards bring multiple advantages for end users in terms of flexibility. It will be much easier to change the entire smart building systems running protocol and hardware that support that particular protocol with a new one by only changing cards, interconnections set through the meshup process remaining the same.

By using web technology based systems makes much easier the update, monitoring, meshup and interconnection processes; this is why I strongly believe that this technology will help to solve multiple problems like interoperability, scalability, system upgrade and costs that are the most important issue why smart building systems didn’t get widespread.

Acknowledgment

This work was supported by the project “Doctoral studies in engineering sciences for developing the knowledge based society-SIDOC” contract no. POSDRU/88/1.5/S/60078, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

This project hardware and software costs were supported entirely by Innolinetech.com.

REFERENCES

[1] Szalontai Levente, Lelia Feştilă, „Multiprotocol wireless hvac control system and sensor monitoring for intelligent buildings", International Conference, 16th Building Services, Mechanical and Building Industry days, 14-15 October 2010, Debrecen, Hungary, ISBN 978-963-473-423-9
[2] Energy Information Administration, http://www.eia.gov/totalenergy/data/annual/index.cfm
[3] European Environment Agency (EEA), http://www.eea.europa.eu/data-and-maps/figures/final-electricity-consumption-by-sector-4
[4] P3 International, http://www.p3international.com/products/consumer/index.html
[5] Onzo Ltd. http://www.onzo.co.uk/
[6] DIY Kyoto http://www.diykyoto.com
[7] Watts Up, https://www.wattsupmeters.com/secure/index.php

SZALONTAI LEVENTE received B.Sc. degree in computer engineering from the Dennis Gábor University, Hungary in 2005, a B.Sc. and M.Sc. degrees in electronics from the Technical University of Cluj-Napoca, Romania in 2007 and 2009 respectively. He is currently Ph.D. student at the Technical University of Cluj-Napoca, Department of Basics of Electronics. His research interest include digital electronics, microcontroller based hardware systems, smart building systems, Internet of Things, medical devices, Software Defined Radio, communication protocols, FPGA circuits, sensors, Wireless Sensor Networks and others.
Personal web page: http://www.innolinetech.com/people/szalontai_levente.htm