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A Cost-effective Standalone Multisensory System for Energy Consumption and CO_2 Emissions Control in Smart-Homes via Internet and Mobile Devices, Using a Network of Arduino Microcontrollers

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Abstract

Because of the global climate change, there is increasing need to control energy consumption and the rate of CO2 emissions into the atmosphere.

This research presents a novel cost-effective multisensory system using a smart network of four Arduino microcontrollers to collect information from multiple sensors measuring temperature, light, humidity, dust, tilt (for earthquakes) and gas in order to control energy consumption of several household devices, using new technologies such as the Internet and smartphones.

A number of electromechanical components including a colour TFT-LCD display, a DC motor, a step servomotor, boards, photoresistors, switches & LEDs, etc. are connected, to control the whole system.

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The ability to monitor energy consumption in real time is designed to easily inform the users regarding gas release that contributes to global warming as well as to allow consumers to change their attitudes towards energy usage in the near future.

Keywords

Smart-homes; Energy consumption; Arduino; Multisensory system

I. Introduction

Advanced Home Management Systems is a growing field as more and more devices are incorporated in the household. There is an increasing need to develop Smart Home systems to easily inform the user about energy consumption in real time, and enable the remote control of devices.

Many interesting approaches have already been proposed in order to remotely monitor and control household devices.

Nguyen et al. propose a system to monitor and control the heating system in a house using a wireless sensor network [1].

A study of the environmental impact of the build environment in the city of Chania is presented by Maragkogiannis et al. [2].

Jianli et al. present a survey of energy efficiency in buildings and microgrids using networking technologies. They claim that since buildings are a significant source of energy consumption, intelligent buildings will have a great impact on the total CO_2 emissions reduction [3].

Energy and CO_2 efficient scheduling of smart home appliances using a decision aiding framework through Pareto frontier exploration is proposed by Sou et al. [4].

Another study by Junyon [5] conducted the eco-friendly zero-house modelling based on a mobile home network. His model claims self-sufficiency in energy by utilizing renewable-energy generation technologies tapping into solar energy as well as into wind and geothermal power.

Baraka et al. proposes a cost-efficient hybrid system to reduce the total energy consumed by some appliances using wireless Zigbee and wired X10 technologies [6].

Also, Lian et al. use a network of ZigBee and wi-fi technologies to develop an intelligent system to control temperature and humidity via a smartphone [7].

Another interesting idea comes from Tsui and Chan [8], who encourage consumers to reduce their demand during peak load hours. They propose a versatile CP DR optimisation framework for the automatic load management of various household appliances in a smart home.

Fitzpatrick and Smith articulate a set of design concerns that focus on-going research into user experience and more effective feedback on domestic energy consumption [9].

Yoon et al. propose a dynamic demand response controller (DDRC) to respond to real-time prices for peak load reduction [10].

Motivations, requirements and challenges, concerning smart grid communication infrastructures are examined by Yan et al. [11].

The effectiveness of interventions to encourage households to reduce energy consumption is reviewed and evaluated by Abrahamse et al. [12].

Gatersleben et al. researched measurement and determinants of environmentally significant consumer behaviour [13].

A qualitative and quantitative study in the reduction household energy consumption is presented by Brandon and lewis [14].

Barocca et al. developed an automatic wireless sensor monitoring system for civil engineering structures to measure both temperature and humidity inside a concrete structure [15].

Shajahan and Anand developed an energy monitoring system to inform the user in real time about energy consumption of a device via a smart phone application [16], which is similar to our work concerning the part of the connection between the microcontrollers and a smartphone.

This project proposes a Smart Home system integrating four Arduino microcontrollers to monitor and control household devices in real time via a smartphone.

The system receives data from a variety of sensors in the house regarding lighting, temperature, smoke, gas, humidity and tilt (for earthquakes) in order to control devices.

The central controller, an Arduino Ethernet Rev. 3 with PoE (Power over Ethernet), provides Internet connection between the system and a smartphone to supervise the function of three microcontrollers, connected with several electromechanical components. Current sensors provide real-time measurements to calculate energy consumption, energy cost and CO_2 emissions.

The system communicates with two online platforms, *ThingSpeak* [19] for visualisation of the sensors data, and *Blynk* [20] to control the system via a smartphone.

II. The Multisensory System Architecture

The proposed system integrates four Arduino microcontrollers and several other electromechanical components (Fig. 1).

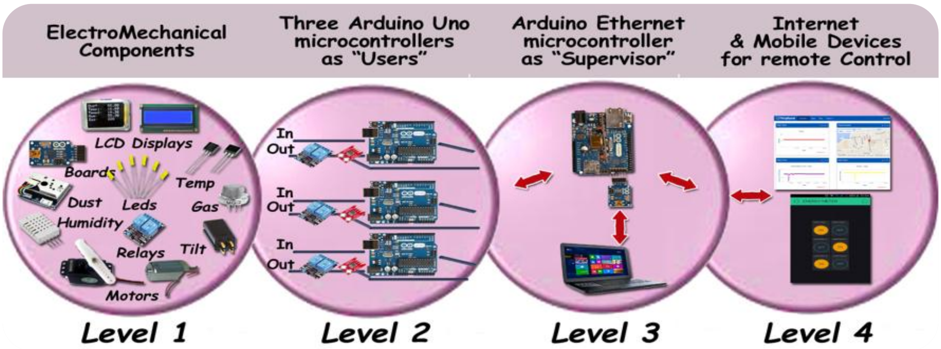

Fig. 1. Architecture of the proposed Multisensory System

At the heart of the system (Fig.1 - Level 3) is an Arduino Ethernet Rev. 3 with PoE (Power over Ethernet) microcontroller fulfilling three roles:

Firstly, it supervises three Arduino Uno microcontrollers (Fig.1 - Level 2) which are connected with several sensors and devices (Fig.1 - Level 1), in order to receive information and control their function.

Secondly, with the aid of ACS712 Sparkfun Hall-Effect Current Sensors (Fig. 12) in serial mode with the three microcontrollers, it calculates energy consumption and CO2 emissions in real-time (Section 3).

Thirdly, the ability to connect to the Internet enables the transmission of the sensors' data to two online platforms (Fig.1 - Level 4), ThingSpeak for visualization and Blynk for remote control of home devices (Section 4). For communication between the computer and Arduino Ethernet board, to upload the program, a USB mini serial adapter is used (Fig. 2).

Fig. 2. USB2Serial (USB mini) Adapter [18]

The proposed system, integrates several sensors to measure a variety of parameters in the internal and external environment of the building, including light intensity, air temperature, air relative humidity, CO2 concentrations, dust particles, and tilt (Fig. 3(a, b)).

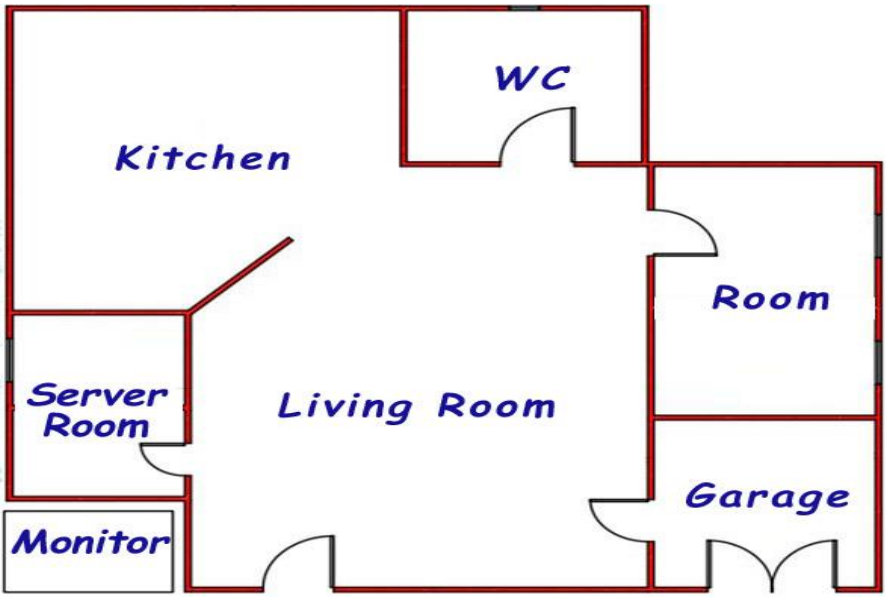

Fig. 3a. Architectural Model of the Building - Design

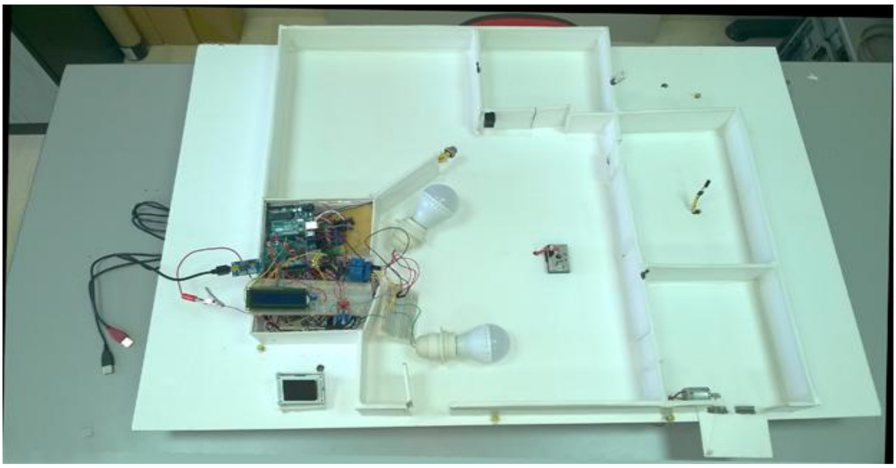

Fig. 3b. Architectural Model of the Building - Implementation

Each one of the three Arduino Uno microcontrollers is assigned a task.

The first one receives information from photoresistors (LDRs) to control the internal and external lighting systems of the building.

The second microcontroller is assigned the "Home Security System".

In case of an Earthquake, the information from the tilt sensor activates the following scenario: If people are present, it turns on the emergency lights, activates the buzzer, and opens the front door and the garage door to evacuate the building (Fig. 4).

Fig. 4. Servo Motor and Tilt sensor

A DC motor is used to operate the garage door and an H-Bridge to invert polarity of the motor (open/close door).

Fig. 5. DC motor & H-Bridge

The second microcontroller is also connected to a GP2Y1010AU0F dust sensor and a TMP35LM temperature sensor, installed close to the fireplace, to detect high concentrations of smoke and fire (>40^{o}C), respectively (Fig. 6 and Fig. 8).

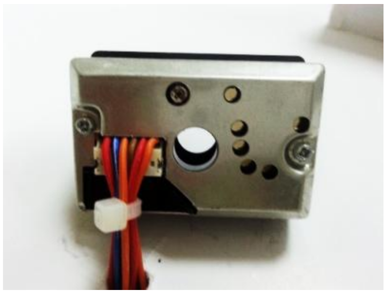

Fig. 6. Dust sensor GP2Y1010AU0F

Moreover, an MQ2 gas sensor in the main room detects gas, propane, methane, hydrogen or smoke. In case of detection of ¬more than 320ppm (parts per million), it activates the buzzer for 10 seconds and switches off the gas system (Fig. 7).

Fig. 7. Gas sensor MQ-2

The third one is designed to control home devices. It receives measurements for temperature (TMP36GZ sensor) and humidity (RHT03 sensor), which are located in the living room, to control the central heating system, the air-conditioning system and humidifiers (Fig. 8).

Fig. 8. Temperature sensors TMP36GZ / TMPLM35 and Humidity sensor RHT03

Since the operating voltage of Arduino Ethernet board is 5 Volts, in order to control high power devices and other equipment in a Smart House, Arduino 2-Relay modules are used (Fig. 9).

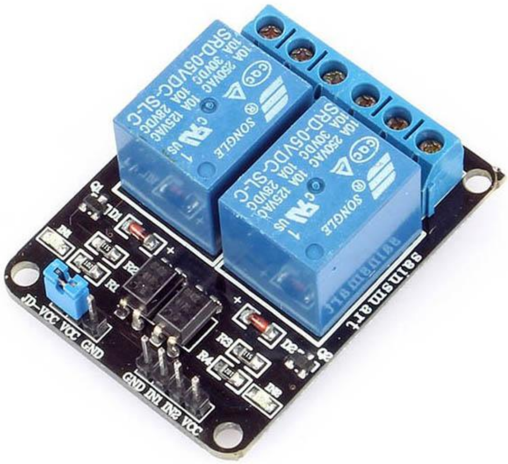

Fig. 9. Arduino 2-Relay Module

To operate the above systems, a multi-output power supply board is developed to deliver 5, 9 & 12 Volts to the various electromechanical components (Fig. 10).

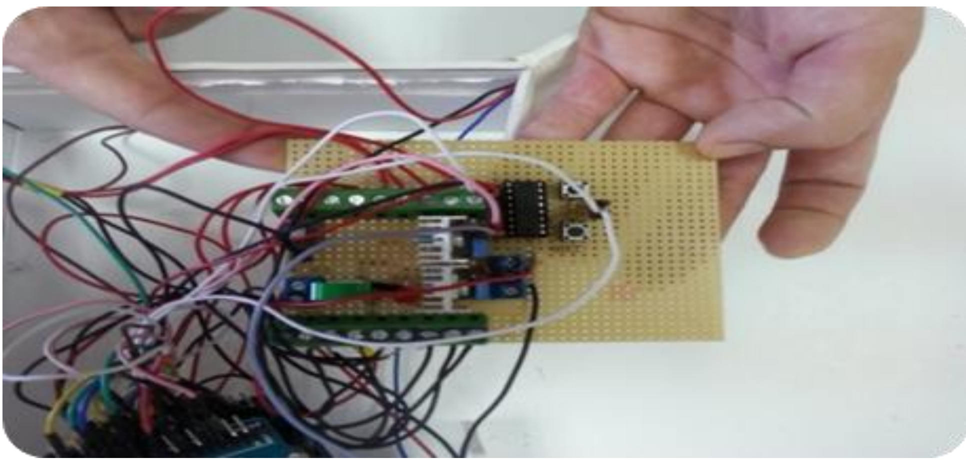

Fig. 10. Multi-Output power supply board (5, 9 & 12 Volts)

III. Energy Consumption and CO_2 Emission Measurements

The proposed system provides real-time voltage and current measurements and calculates the energy consumption, the energy cost and the rate of CO_2 emissions into the atmosphere.

$$P = V * I \qquad (1)$$

where P = Power (watts, W), V = Voltage (Volts, V) and I = Current (Amperes, A)

Arduino Ethernet has onboard analog input pins which receives values in the range of 0 - 1023 and it is necessary to convert them to correspond to the maximum range 0 - 5 Volts.

For example, for a load of two 12-Volt lamps, we need a voltage divider to shift voltage in the range of 0 - 5 Volts. To calculate the exact value of the voltage we need the following chart:

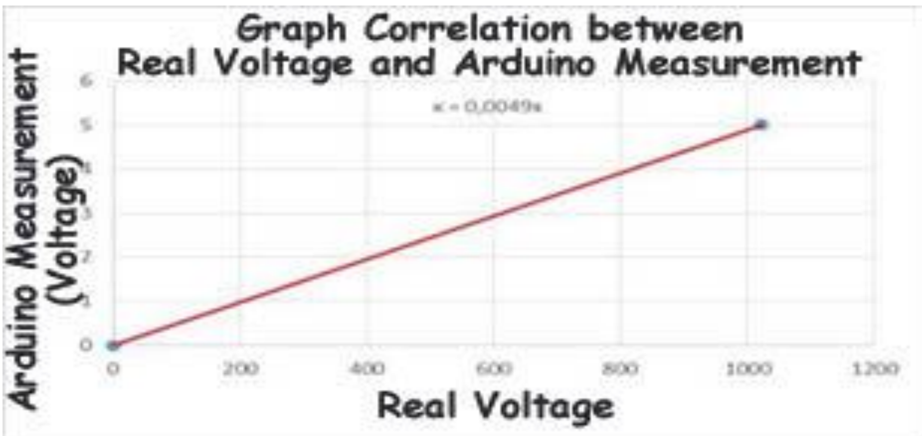

Fig. 11. Graph Correlation between Real Voltage and Arduino Measurement (Voltage)

The following formula defines the Gradient in the above graph:

$$k = (y2 - y1)/(x2 - x1) =$$
$$(5 - 0)/\,(1023 - 0\,) = 5\,/\,1023 = 0.0049 \qquad (2)$$

Since the Gradient is known, the real Voltage value can be calculated by the following formula:

$$Real\ Voltage = 0.0049\,V * 3 * AAP\ value \qquad (3)$$

where AAP = Arduino Analogue Pin value

To define the real Voltage, we multiply by three, since the Voltage divider used at the beginning of the circuit divides the input Voltage by three.

For the calculation of the current, ACS712 Sparkfun Hall-Effect sensors are connected in serial with the loads to give precise current measurements (Fig. 12).

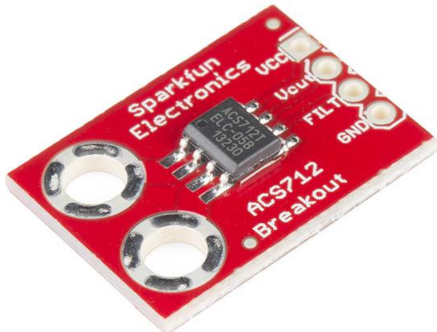

Fig. 12. ACS712 Sparkfun Hall-Effect Current Sensor

Due to the high-level of noise at the output of the sensor, we get the average of 1000 measurements per second, instead of one.

Once *Electric Power* is calculated, the *cost of the consumed electric energy* per hour and the corresponding *CO2 emissions* can also be calculated.

Electric Energy Consumption Cost (4) is defined by multiplying the *Electric Power* times the *hours used* times the *cost per hour* (Watts-hour).

$$Cost = Watts * Hours\ Used * Cost\ per\ hour \qquad (4)$$

CO_2 emissions measurement (5) is determined by multiplying *Electric Power* with *CO2 mass emissions* per Watts-hour (Wh), produced during the generation of this electric energy.

$$CO2\ Emmissions = EP * CO2MA \qquad \text{/Watts-hour} \qquad (5)$$

where EP is Electric Power and CO2MA is CO2 Mass Emissions

Finally, the *total Electric Energy Consumption* and the *total CO2 emissions* of the proposed system are defined by the sum of measurements of every current sensor used.

IV. Remote Control of the System via Internet and Mobile Devices

The multisensory system presented in this project, integrates an Arduino Ethernet Rev.3 with PoE (Power over Ethernet) microcontroller connected to the Internet, for the remote control of the household devices.

Two online IoT (Internet of Things) platforms are used for data collection, visualisation and control.

Firstly, for the continuous collection and storage of uploaded sensor data in the cloud and real-time analysis and visualization, *ThingSpeak* [19] is used.

As a first step, the user needs to create an account and then, with the aid of a graphical interface and libraries acquires measurements in the form of charts.

Additionally, it is important that the user can be informed about energy consumption of the house devices in real-time (Fig. 13).

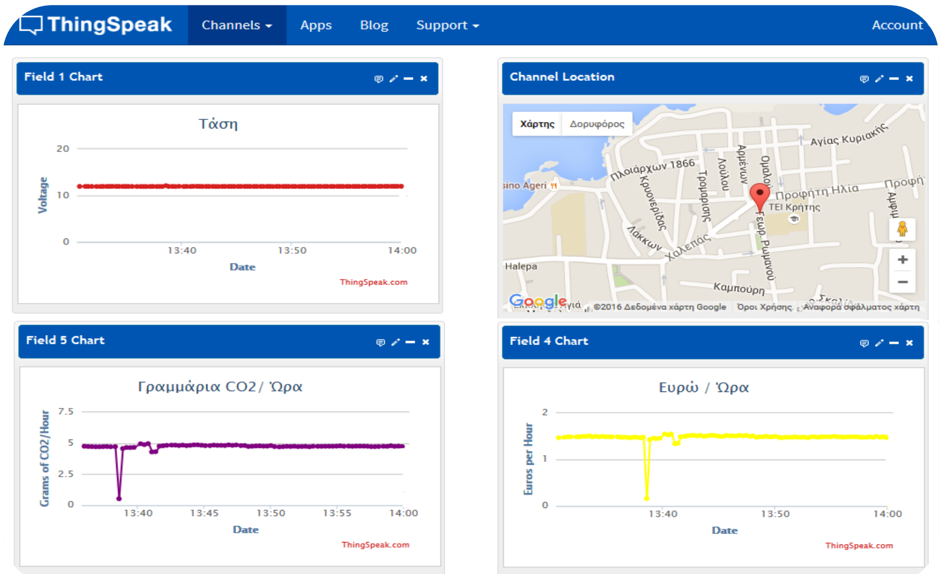

Fig. 13. Real-time Calculation and Monitoring of CO2 Emissions and Electrical Energy Consumption Cost of Home devices

Blynk [20], another online IoT platform for iOS (iPhone Operating System) and Android applications, is used for the remote control of the system with a smartphone, over the Internet.

Using widgets such as buttons, graphs, sliders, etc. provided by *Blynk*, the user creates a smartphone interface for the proposed system in order to control home devices (Fig. 14).

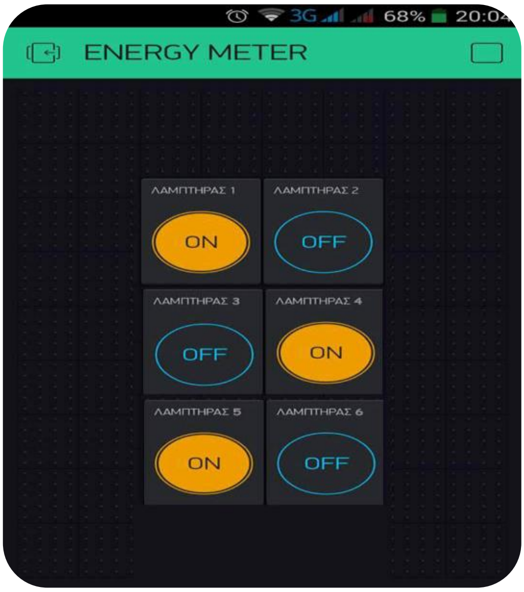

Fig. 14. Example of SmartPhone Interface for Real-time Control of Home Devices

V. Conclusion

This research presents a novel multisensory system of a Smart-Home, to calculate and control energy consumption and the rate of CO2 emissions into the atmosphere, via the Internet and mobile devices.

Using a network of four Arduino microcontrollers the system receives information from multiple sensors to control several devices through their energy consumption, applying a novel “Supervisor & Users” technique.

The idea is based on the real world, where several people are assigned different tasks and a supervisor oversees and regulates their work. In a similar manner, an Arduino Ethernet oversees the work of three Arduino Uno microcontrollers which are responsible for controlling the lighting system, the security system, and the operation of the other household devices.

Even though fewer microcontrollers could be used, we decided to use four microcontrollers in order to have the ability to expand the system’s functionality including also other electromechanical household components and devices in the future (e.g. add sensors and devices for a anti-theft security system).

Moreover, in Greece, a country with seismic activity, the next step is to integrate to the system the capability to receive data from the tilt sensors of several houses of the area via the Internet, for greater accuracy of earthquake predictions.

The operation of the system is at no cost, since the two online visualisation and control platforms which are used for the control of the devices, are free of charge.

Monitoring of house energy consumption with the proposed system, contributes to the increase of environmental awareness, encouraging people to conserve energy and change their attitudes of energy usage in the near future.

References

[1] Nguyen, N., Tran, Q., Leger, J., & Vuong, T. "A real-time control using wireless sensor network for intelligent energy management system in buildings", IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems (EESMS 2010), Proceedings, 87-92, 2010. DOI: https://doi.org/10.1109/EESMS.2010.5634176

[2] Maragkogiannis, K., Kolokotsa, D., Maravelakis, E., & Konstantaras, A. "Combining terrestrial laser scanning and computational fluid dynamics for the study of the urban thermal environment", Sustainable Cities and Society, 13, pp. 207-216, 2014.DOI: https://doi.org/10.1016/j.scs.2013.12.002

[3] Pan, J., Jain, R., & Paul, S. "A survey of energy efficiency in buildings and microgrids using networking technologies", IEEE Communications Surveys and Tutorials, 16(3), pp.1709-1731, 2014. DOI: https://doi.org/10.1109/SURV.2014.060914.00089

[4] Sou, K. C., Kordel, M., Wu, J., Sandberg, H., & Johansson, K. H. "Energy and CO2 efficient scheduling of smart home appliances", European Control Conference (ECC 2013), pp. 4051-4058, 2013.

[5] Kim, J. "CO2 zero-house design with mobile smart home technology", International Journal of Multimedia and Ubiquitous Engineering, 9(2), pp. 357-362, 2014. DOI: https://doi.org/10.14257/ijmue.2014.9.2.36

[6] Baraka, K., Ghobril, M., Malek, S., Kanj, R., & Kayssi, A., "Low cost arduino/android-based energy-efficient home automation system with smart task scheduling", 5th International Conference on Computational Intelligence, Communication Systems, and Networks (CICSYN 2013), pp. 296-301, 2013. DOI: https://doi.org/10.1109/CICSYN.2013.47

[7] Lian, K., Hsiao, S., & Sung, W., "Intelligent multi-sensor control system based on innovative technology integration via ZigBee and wi-fi networks", Journal of Network and Computer Applications, 36(2), pp. 756-767, 2013. DOI: https://doi.org/10.1016/j.jnca.2012.12.012

[8] Tsui, K. M., & Chan, S. C., "Demand response optimization for smart home scheduling under real-time pricing", IEEE Transactions on Smart Grid, 3(4), pp. 1812-1821, 2012. DOI: https://doi.org/10.1109/TSG.2012.2218835

[9] Fitzpatrick, G., & Smith, G., "Technology-enabled feedback on domestic energy consumption: Articulating a set of design concerns", IEEE Pervasive Computing, 8(1), pp. 37-44, 2009. DOI: https://doi.org/10.1109/MPRV.2009.17

[10] Yoon, J. H., Baldick, R., & Novoselac, A., "Dynamic demand response controller based on real-time retail price for residential buildings", IEEE Transactions on Smart Grid, 5(1), pp. 121-129, 2014. DOI: https://doi.org/10.1109/TSG.2013.2264970

[11] Yan, Y., Qian, Y., Sharif, H., & Tipper, D., "A survey on smart grid communication infrastructures: Motivations, requirements and challenges", IEEE Communications Surveys and Tutorials, 15(1), pp. 5-20, 2013. DOI: https://doi.org/10.1109/SURV.2012.021312.00034
[12] Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T., "A review of intervention studies aimed at household energy conservation", Journal of Environmental Psychology, 25(3), pp. 273-291, 2005. DOI: https://doi.org/10.1016/j.jenvp.2005.08.002
[13] Gatersleben, B., Steg, L., & Vlek, C., "Measurement and determinants of environmentally significant consumer behavior", Environment and Behavior, 34(3), pp. 335-362, 2002.
[14] Brandon, G., & Lewis, A., "Reducing household energy consumption: A qualitative and quantitative field study", Journal of Environmental Psychology, 19(1), pp.75-85, 1999. DOI: https://doi.org/10.1006/jevp.1998.0105
[15] Barroca, N., Borges, L. M., Velez, F. J., Monteiro, F., Górski, M., & Castro-Gomes, J., "Wireless sensor networks for temperature and humidity monitoring within concrete structures. Construction and Building Materials", 40, pp. 1156-1166, 2013.
[16] Shajahan, A. H., & Anand, A., "Data acquisition and control using arduino-android platform: Smart plug", International Conference on Energy Efficient Technologies for Sustainability (ICEETS 2013), pp. 241-244,2013.DOI: https://doi.org/10.1109/ICEETS.2013.6533389
[17] https://www.sparkfun.com/products/8882 (accessed September 20, 2016)
[18] https://www.arduino.cc/en/Main/USBSerial (accessed September 20, 2016)
[19] https://thingspeak.com (accessed September 20, 2016)
[20] http://www.blynk.cc (accessed September 20, 2016)