P21

Energy consumption and environmental conditions measuring system based on Arduino/Raspberry PI

G. SKVARČ BOŽIČ, A. MARINŠEK, U. HUDOMALJ, I. HUMAR, M. UMBERGER
Faculty of electrical engineering, University of Ljubljana
Slovenia

SUMMARY

The majority of consumed energy in shopping centers is due to refrigeration technique [1]. Some of the subsystems in refrigeration are dependent on environmental factors, which usually drastically change. Therefore we can adjust their working regime to the conditions, thus save on energy. In order to explore energy consumption characteristics of a refrigeration system, a measuring system to collect information about the environmental conditions and electrical consumption is needed.

We designed and implemented an independent versatile system, which does not interfere with the existing installations and is capable of synchronously measuring power and energy consumption of up to six one phase loads or two three phase loads, temperatures on up to twenty-one positions at once, humidity, and door opening frequency. It offers remote access of gathered data, stored in two remote cloud storages, and thus enables user-friendly web visualization. The system consists of two open source platforms known as Arduino and Raspberry Pi (RPi). The Arudino is primarily used for measuring electrical loads while keeping track of other relevant data of the surroundings. All of the collected data is periodically transmitted to the Raspberry Pi, which serves as a local base and a gateway to the internet.

We used the system in a real environment to measure energy consumption of secondary loads in refrigeration while measuring environmental conditions. With the help of the gathered data, we are planning to efficiently adjust the operational regime of an appliance and economize energy expenses.

KEYWORDS

Electrical energy consumption, measuring system, temperature, humidity, door opening frequency, Arduino, Raspberry Pi, shopping center, refrigeration

gasper.skvarc@gmail.com

1. INTRODUCTION

With the constant development of our global society, industry and living standards there is also an increasing demand for electrical energy. Because of the limited energy resources and the growing environmental awareness a lot of effort is put to lower energy consumption, which is also appealing because of economic benefits [1, 2].

Shopping centers are amongst the biggest consumers of electrical energy as it is estimated that they can account for up to 3 per cent of national energy consumption [3] and form 50 to as much as 80 per cent of a shopping center's total consumption is due to refrigeration technique [1, 4]. Hence the refrigeration technique as a big energy consumer presents a large potential for optimization, resulting in economical and energy savings.

The main sources of power consumption in refrigeration are compressors, which transfer heat from a cold to a hot reservoir [1, 5]. However other so-called secondary loads, e.g. anti-sweat heaters, are not negligible. Many of the secondary loads are dependent on environmental factors for example temperature, humidity, and day length [6, 7].

These appliances are built to function in the worst estimated environmental conditions. The conditions usually drastically change. Therefore we can adjust their working regime to the conditions, thus save on energy.

In our other study [8] we have dedicated ourselves to minimizing energy consumption by altering the working regimes of appliances depending on the surroundings and the load of the electrical grid. Hence a measuring system to collect data about the environmental and electrical conditions is needed. There are already systems on the market, which measure some of these quantities, but none of them provide synchronous measurements of all the environmental and electrical parameters on a single platform. Many of them are also hard to implement into existing installations without interfering and are therefore impractical for testing in realistic environments.

That is why we designed an independent system, which does not interfere with the existing installations and is capable of measuring power and energy consumption, temperature, humidity and door opening frequency. It also includes user-friendly web visualization for remote access and more convenient analysis of the gathered data.

The system consists of two open source platforms known as Arduino [9] and Raspberry Pi (RPi) [10]. The Arduino is primarily used for measuring electrical loads with current clamps [11]. The system is built to simultaneously measure up to six independent one phase loads or two three phase loads. It also keeps track of other relevant data, such as temperatures on up to twenty-one positions at once by using 1-Wire temperature sensors [12], humidity [13], and door opening frequency using generic reed switches [14].

All of the collected data is with the help of 2.4 GHz radio transceivers periodically transmitted to the Raspberry Pi, which serves as a local base and a gateway to the internet. Connected to the Raspberry is a 3G USB dongle, which maintains connection to two remote cloud storages. One is Dropbox [15], where we store raw data, and the other is Emoncms - an open source web application used for data visualization [16].

2. MEASURING SYSTEM

The process of measuring, data gathering and analysis begins at one of four different sensors: YDHC SCT-013 [10] current transformers (CT) as electrical current sensors, 1-Wire temperature sensors DS18B20 [11], humidity sensor HIH 4000 and generic door opening frequency sensors [14]. On the Arduino the sensor readings are analysed and converted into meaningful values for humans to read (e.g. the voltage drop on the humidity sensor is converted to relative humidity). These values are not permanently stored on the Arduino, instead they are periodically wirelessly transferred to a local database on the Raspberry Pi. For the purpose of wireless communication the 2.4 GHz frequency band was used. To give the measurements additional meaning, a timestamp is added to each individual measurement curtesy of a custom-made shield fitted to the Arduino.

The local base must offer adequate local storage and must be capable of handling several tasks simultaneously, as besides storing data locally, it acts as a gateway to the internet in order to upload data to remote cloud storages. To that end, we used the Rapberry Pi (RPi) as our local base, which is connected to the internet via a 3G dongle.

After all of the data has been analysed and gathered, it is uploaded to two remote cloud storages for remote public access. The first is Dropbox, where raw data is stored and the second is Emoncms – an open source application, where raw data is refined and visualized. In this view the measuring process is divided into three sections: measurement, storing and visualisation.

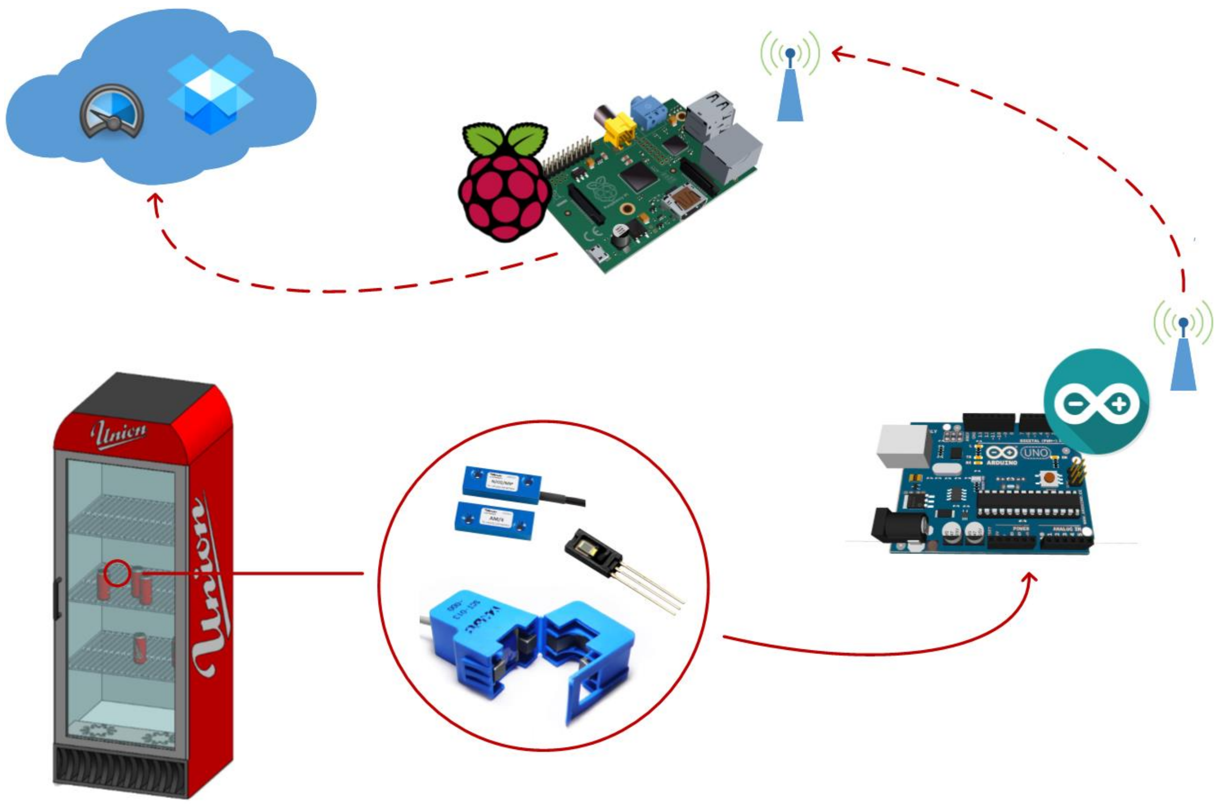


Figure 1: Measuring system components

2.1. ARDUINO AND RASPBERRY PI

Two platforms were used for designing the measuring system: Arduino and Raspberry Pi. The former is used for collecting sensor values, whereas the latter is used for data storage and remote access.

Arduino, the business end of the measuring system, is used for interpreting sensor values and parsing them on to the RPi. With the addition of an Emoncms shield (EmonTx) [16] and a custom-made shield the Arduino is capable of measuring power and energy consumption, temperature, humidity and door opening frequency, while keeping track of accurate time.

Arduino is an open source platform with its own integrated development environment (IDE), large online community and an abundant collection of libraries. The Arduino offers a variety of pins, of which the following will be used for different sensors: an analog pin for each CT, one digital pin for a series of temperature sensors (1-Wire protocol), an analog pin for the humidity sensor and a digital pin for each of the door opening frequency sensors. Furthermore the MISO, MOSI and SCK pins are used by the 2.4 GHz transceivers, the I2C bus is used by the real time clock and both supply voltages are used for supplying power to all of the components.

Upon receiving sensor values, each Arduino interprets the values and translates them into a meaningful format for humans to read (i.e. the voltage drop on the CT’s burden resistor is translated into current draw). The data is then compressed into packets and sent wirelessly to the RPi.

Raspberry Pi 2 B+, the core of the measuring system is used for communication and data collecting from Arduinos, data storing and uploading it to the cloud. The latter is achieved by connecting the RPi to the internet, hence making it an internet gateway.

The RPi is a low cost small-sized computer, which offers 40 digital I/O pins, 4 USB ports and an Ethernet port. Its main use is for educational purposes and concept design testing. On top of the RPi sits a quad-core ARM Cortex-A7 processor with 1 GB of RAM, giving it multitasking capabilities equivalent to a smartphone.

The RPi is used as a local base and a gateway to the internet. It collects data from the Arduino, stores it locally and uploads it to two remote cloud storages. For establishing a connection between the Arduinos and RPi the measuring system takes advantage of the 2.4 GHz frequency band. The connection between both platforms is ensured using nRF24L01 [17] radio transceivers with a maximum sent packet size of 32Bytes and an ideal range of 100 meters.

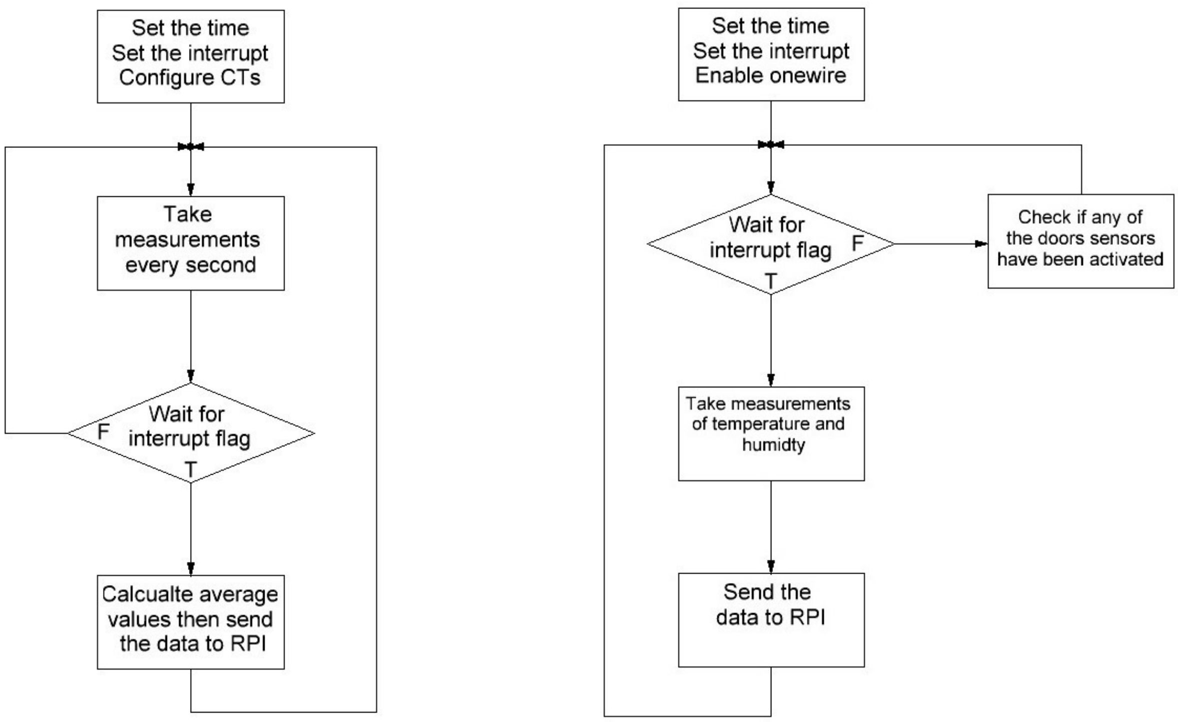


Figure 2: Arduino program flow for electrical current (left) and temperature measuring (right)

2.2. MEASURED QUANTITIES

The described measuring system is used for measuring four different quantities, while collecting data on a single device. The sensors used for the measuring system are all easy to use, widespread and thus low-cost.

The main measured quantity is electrical current. Owing to the CTs split core, they can be split apart, mounted onto an electrical conductor (wire), while current is running through it and put back together, without disconnecting the conductor. Due to non-linearity the CT has a measuring accuracy of 3%, while core saturation starts at 100 A (max current).

The CTs use advantage of electrical induction and their output is a voltage drop on a burden resistor connected to the wire wound around the split core. When monitoring smaller loads (lower currents) the burden resistance should be increased in order to maximize measurement resolution. A 33 Ω resistor is used for 100 A RMS currents so in this view a 66 Ω resistor would be used for 50A RMS currents to aid measurement accuracy.

To maximize measurement resolution, the voltage across the burden resistor at peak current should be equal to half that of the Arduino's analog reference voltage. The complete equation for the burden resistor is:

$$R_b = \frac{Aref}{2} * \frac{K_I}{\sqrt{2} * I} \quad , \qquad K_I = \frac{N_p}{N_s}$$

In total the measuring system consists of eight CTs, which results in the possibility to measure the same amount of one phase loads or 2 three phase loads, where two CTs are redundant.

The most numerous sensors of the measuring system are the DS18B20 temperature sensors [11]. Three temperature chains, each incorporating seven 1-Wire temperature sensors results in a total of twenty one temperature sensors. With a measuring range from – 55 to 125 degrees Celsius and a measuring accuracy of 0.5°C the sensors can be used for measuring anything from room temperature to the temperature inside a refrigerator.

For measuring humidity the system uses an analog HIH 4000[12] humidity sensor. Its main trait is a near linear relation between output voltage and relative humidity (RH). In our case the humidity sensor is used to monitor RH inside a shopping center and adjust refrigeration anti-sweat heaters accordingly.

The fourth sensor is a generic reed switch [13]. The reed switch is used for door opening frequency measuring. It consists of two separate parts: a magnet mounted on the door casing and a switch mounted on the top rail of the door. Each time the door opens the switch is turned off and a measurement is made. In our case a counter is increased by one each time a door is opened. The measuring system consists of five reed switches.

Although not a sensor, the real time clock (RTC) DS3231 [18] is part of the measuring system. It is located on a custom-made shield attached to each of the Arduinos. It serves for accurate time keeping, so that a timestamp is added to each individual measurement taken. Its combined yearly correction accounts to one minute.

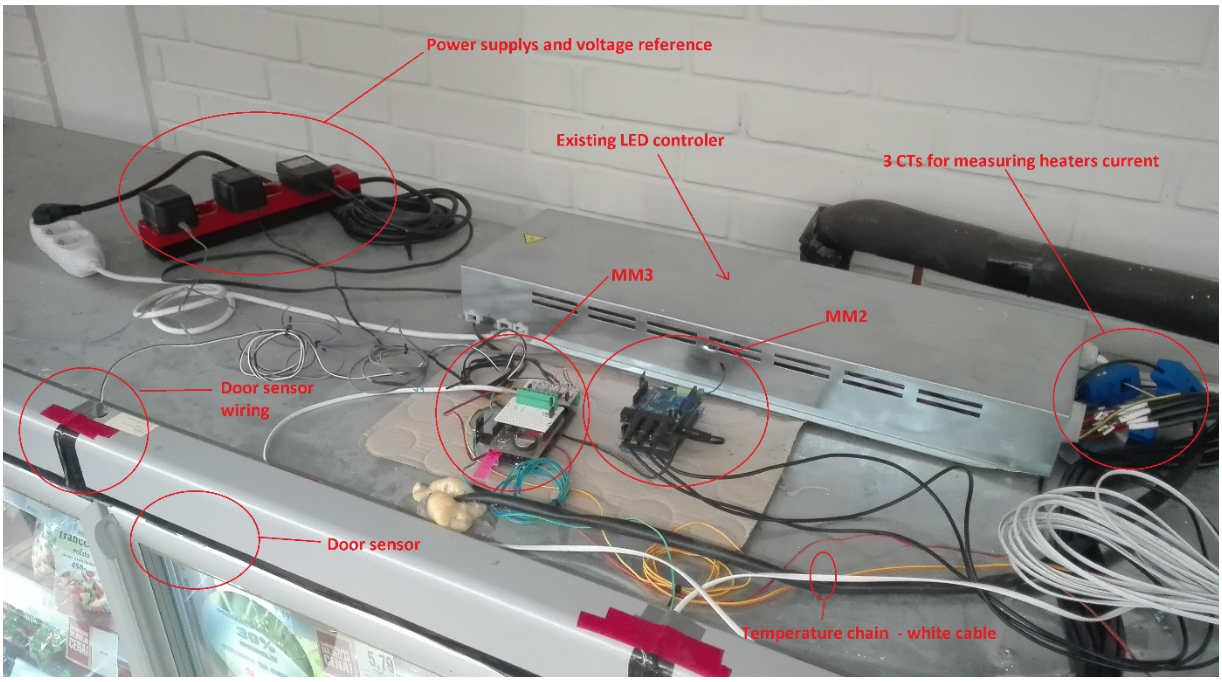


Figure 3: Implémentation of the measuring system

2.3. VISUALIZATION

The final step of the measuring process is uploading and visualizing data. With the help of a 3G dongle and free cloud storage solutions, the measuring system is able to upload a copy of measurement data to two cloud storages for remote access and visualization.

Received data on the RPi is grouped in a single csv-file and stored locally onto the RPi's MicroSD card. The same text file is then uploaded to Dropbox [14] on an hourly basis, where the latest copy of raw measurement data resides at all times. This data is intended for further analysis with tools such as Excel and Matlab. The upload to Dropbox is achieved using Dropbox's API.

While receiving measurement data every minute, the RPi simultaneously packs all electrical load measurement data and makes a HTTP request to Emoncms [15]. Emoncms is an open source web application intended for collecting electrical load measurement data and visualizing it using various graphs and charts. Each user is either given login credentials to an account with pre-designed visualization tools, or the user is given a unique account where he has access to a private dashboard, that he can customize according to his needs. Emoncms offers real time data visualization, electrical energy consumption calculation.

In the case of a poor internet connection the upload to Dropbox and Emoncms is interrupted, while the local copy of data keeps on updating itself every minute. Once the internet connection is restored, the measuring system automatically reconnects to both cloud storages.

3. RESULTS

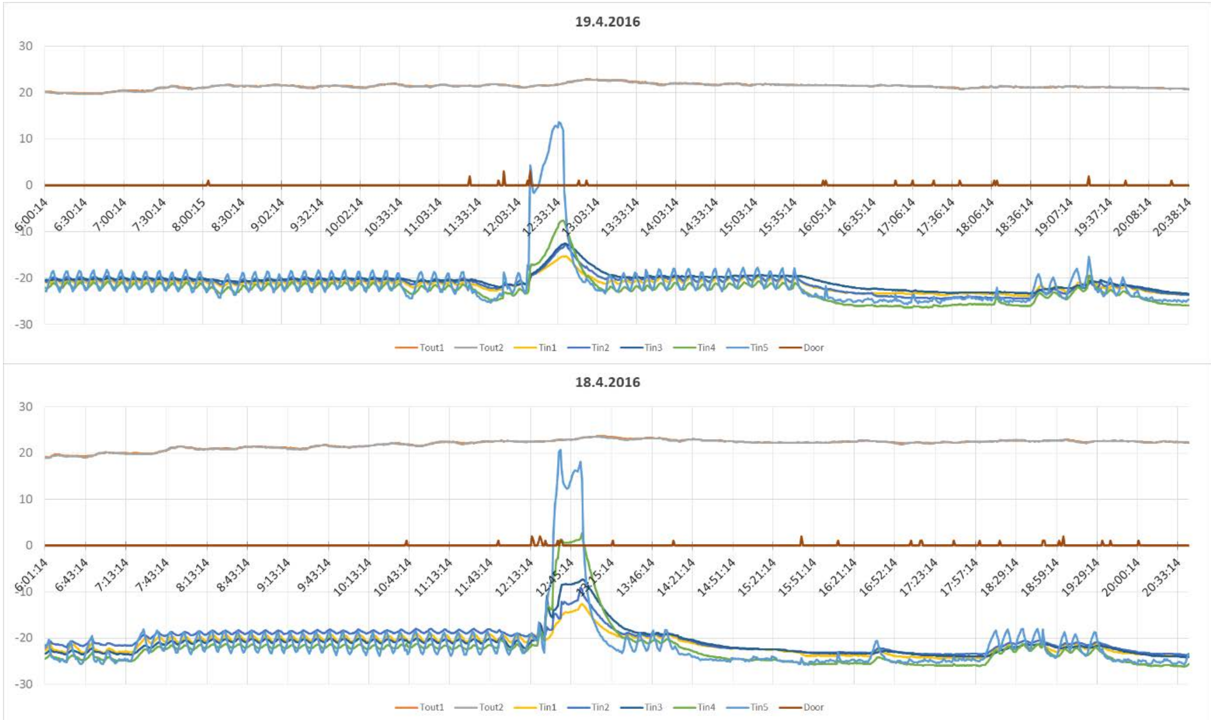
The goal of designing our own measurement system was to better understand the phenomena that take place inside a grocery store refrigerator. Understanding them and discovering correlations between different measured quantities can lead to new dependencies, which in term dictate the operational regime for secondary loads inside a refrigeration unit.

Two of six doors were fitted with generic reed switches and inside the refrigerator, between both doors, five temperature sensors were mounted evenly across the height of the refrigerator. The chosen two doors were the ones that get the most traffic during opening hours. The temperature sensors were mounted in close proximity to the door mullion.

The first collected results using our measuring system show a minor correlation between door opening frequency and inside temperature. The bellow graphs show the above-mentioned dependency on two consecutive days, where a rise in inside temperature can be seen both days between 18:00 and 20:00. The temperature fluctuation occurred in the time when occupancy in the shopping center, where the measurements were made is biggest. The maximal recorded temperature rise in this period was 8°C. Additionally, both graphs show a major rise in refrigerator inside temperature during the defrosting period at around twelve o'clock.

Furthermore, the humidity inside a shopping center (the refrigerators surroundings) has an effect on the condensation on refrigerator door windows. Relative humidity is subject to the geographical location and it changes depending on visitor count, due to weather conditions, and it also changes during different times of the year. Changes in relative humidity are most noticeable in smaller grocery stores, as they are not fitted with chillers. The former are commonly fitted to larger shopping centers, but operate with a delay due to the large quantity of air inside the shopping center.

Anti-sweat heaters and their operational regime offer great room for improvement, as they do not keep track neither of door opening frequencies, nor the humidity inside the shopping center. We have yet to determine how the latter impacts condensation on door windows, as it will take a long-term experiment.



Graph 1: Correlation between inside refrigerator temperature and door opening frequency

4. CONCLUSION

In order to explore energy consumption characteristics of a refrigeration system, a measuring system to collect information about the environmental and electrical conditions was needed. Therefore we designed an independent versatile system, which does not interfere with the existing installations and is capable of synchronously measuring power and energy consumption of up to six one phase loads or two three phase loads, temperatures on up to twenty-one positions at once, humidity, and door opening frequency. It offers remote access of gathered data, stored in two remote cloud storages, and thus enables user-friendly web visualization.

We have successfully tested and implemented the system in a real environment to measure energy consumption of secondary loads in refrigeration while measuring environmental conditions. In this article we have presented how our measuring system can be used to measure inside temperature of a refrigerator depending on door opening frequency. With the help of the gathered data we have evaluated how the opening of doors in a refrigerator affects the inside temperature. We discovered considerable dependence as the inside temperature rose for as much as 8°C because of door openings.

We are going to use the gather data in one of our other studies, where we are researching energy consumption of anti-sweat heaters depending on environmental conditions, e.g. humidity, and door opening frequency. With the help of our system, we are planning to efficiently adjust the operational regime of anti-sweat heaters, thus save on energy. We are going to further develop the system's functionalities by implementing the ability to control the operational regime of appliances using the gathered data.

5. BIBLIOGRAPHY

[1] Š. Vidrih, "Strategije za optimizacijo stroškov porabe električne energije hladilne tehnike v nakupovalnih središčih," (Master's thesis, University of Ljubljana, Faculty of Engineering, 2014)

[2] B. K. Bose, "Global Warming: Energy, Environmental Pollution, and the Impact of Power Electronics" (IEEE Industrial Electronics Magazine, vol. 4, pp. 6-17, 2010)

[3] Arias J., "Lundqvist P., Heat recovery and floating condensing in supermarkets" (Energy and Buildings, 38 (2006), No. 2, 73-81)

[4] T. G. Hovgaard, L. F. S. Larsen, M. J. Skovrup, and J. B. Jørgensen, "Power consumption in refrigeration systems - modeling for optimization" (International Symposium on Advanced Control of Industrial Processes, IEEE. Hangzhou, pp. 234–239, 2011)

[5] L. F. S. Larsen, C. Thybo, and H. Rasmussen, "Potential energy savings optimizing the daily operation of refrigeration systems," (Proc. European Control Conference, Kos, Greece, pp. 4759–4764., 2007)

[6] A. Bahman, L. Rosario and M. Rahman, "Analysis of energy savings in a supermarket refrigeration/HVAC system" (Applied Energy, vol. 98, pp. 11-21, 2012)

[7] D. Rauss, S. Mitchell and R. Faramarzi, "Cool Retrofit Solutions in Refrigerated Display Cases" (2008 ACEEE Summer Study on Energy Efficiency in Buildings, pp. 233-244, 2008)

[8] Š. Vidrih, M. Umberger and I. Humar, "Optimization of Electric Energy Consumption Operating Costs in Cooling Technique by Establishing a Remote Central Control System, Exploiting Thermal Capacity and Load shifting" (EuroCon 2013, pp. 1479-1484, 2013)

[9] Arduino (Accessed on: 16.4.2016, Available: http://www.arduino.cc/)

[10] Raspberry Pi (Accessed on: 16.4.2016, Available: https://www.raspberrypi.org/)
[11] YHDC, 100A Split core current transformer SCT-013 ([Online] Accessed on: 17.4.2016, Available: http://www.yhdc.com/en/product/320/)
[12] Dallas Semiconductor, DS18B20 Programmable Resolution 1-Wire® Digital Thermometer ([Online] Accessed on: 16.4.2016, Available: https://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Temp/DS18B20.pdf)
[13] Honeywell, HIH-4000 Series, Humidity Sensor ([Online] Accessed on: 16.4.2016, Available: http://sensing.honeywell.com/honeywell-sensing-hih4000-series-product-sheet-009017-5-en.pdf)
[14] Reed switch ([Online] Accessed on: 16.4.2016, Available: https://en.wikipedia.org/wiki/Reed_switch)
[15] Dropbox ([Online] Accessed on: 16.4.2016, Available: https://www.dropbox.com/)
[16] Emoncms ([Online] Accessed on: 16.4.2016, Available: https://github.com/emoncms/emoncms)
[17] EmonTx Arduino Shield SMT ([online] Accessed on 16.4.2016, Available: https://openenergymonitor.org/emon/emontxshield/smt)
[18] Nordic Semiconductor, nRF24L01 ([Online] Accessed on: 16.4.2016, Available: http://www.nordicsemi.com/eng/Products/2.4GHz-RF/nRF24L01)
[19] Maxim Integrated, DS3231 ([Online] Accessed on: 16.4.2016, Available: http://datasheets.maximintegrated.com/en/ds/DS3231.pdf)