Low Cost Arduino-Based Sensors for Deriving Thermal Parameters of Buildings

Behnam Mobaraki [*, a]**, Seyedmilad Komarizadehasl** [b]**, Francisco Javier Castilla Pascual** [a] **and Jose Antonio Lozano Galant** [a]

[a] Department of Civil and Building Engineering, Universidad de Castilla La Mancha. Spain.
behnam.mobaraki@uclm.es, fcojavier.castilla@uclm.es and Joseantonio.lozano@uclm.es

[b] Department of Civil Engineering and Environmental Engineering, Universitat Politècnica de Catalunya BarcelonaTech, Spain.
seyedmilad.komarizadehasl@upc.edu

ABSTRACT

This article deals with information about low cost temperature sensors in terms of accuracy which is applicable for Structural Health Monitoring (SHM) of buildings. Environmental sensors are practical for deriving thermal parameters of structures and also inferring humidity range of concrete during casting and curing process. The utilized Arduino-based system, measured variations of temperature and humidity in a SELECTA oven. The results indicate that lower range of Standard Deviation (S.D) acquired for the temperature observations (0.04≤ S.D ≤0.13) rather than humidity ones (1.15≤ S.D ≤1.33), which means that the sensor DHT22 is more accurate in terms of measuring temperature rather than humidity.

KEYWORDS: Low Cost Sensors, DHT22, Arduino-Based System, Thermal Analysis, Open Source Platforms.

1. Introduction

Climate change has drastically affected crops, wildlife and people's livelihoods. One of the main elements that can prevent this tragedy is to lessen the energy consumption since this incident could also be caused by burning of the fossil fuels for the human needs. In this way, one of the most efficient solution is to control the waste of energy in the buildings and public places. The development of economically viable Building Information Modelling (BIM) using different software and hardware has become increasingly popular in recent years. An economic Arduino-based embedded system can be defined as combination of Arduino open source platform and low-cost environmental sensors. Studies of the Arduino-based as well as BIM-based controlling systems in different engineering fields were conducted by many scholars.

Barroca et al. in 2013 have designed and Arduino-based controlling system for concrete structures. They have prepared thermal sensors inside the concrete in order to measure temperature and humidity of the concrete at different levels [1]. Different low-cost particle sensors were assessed by calibration methods adapted from the US EPA 2013 Air Sensor Workshop recommendations. The six different elements of the examinations were linearity response, precision of measurements, limit of detection, dependence on particle composition, dependence on particle size, relative humidity and temperature influences [2]. Bamodu et al. in 2017 have used various types of humidity and

Behnam Mobaraki, Seyedmilad Komarizadehasl, Francisco Javier Castilla Pascual and Jose Antonio Lozano Galan / VIII ACHE CONGRESS– SANTANDER 2020

1

temperature low cost sensors such as LM35 and DHT11 in order to control the indoor environment parameters of the buildings, heating, Ventilation, Air-Conditioning (HVACs) [3].

Monitoring ventilation as well as thermal/humidity comfort level of the public places are vital issues since variation of the mentioned parameters might occur in different spaces. Marzouk and Abdelaty in 2014 stablished Wireless Sensor Network (WSN) and BIM-based model in order to be able to monitor thermal condition in the different places of a subway [4]. Kim et al. in 2015 presented the development of Modelica Library for BIM-based building energy simulation using an Object-Oriented Physical Modeling (OOPM) approach and Modelica, an equation-based OOPM language. Using the ModelicaBIM library they have prepared system interfaces between BIM and energy simulation, aiming to stablish semi-automatic translation from BIM to building Energy Modeling (BEM) [5]. Garcia and Kamsu-Foguem in 2019 presented a new approach for automation of building construction when dealing with the energy efficiency for the purpose of predicting comfort levels elements such as heating, ventilating, air conditioning and etc. moreover they stablish BIM for thermal performance of prefabricated construction system [6, 7].

As is evident from the aforementioned studies, the advantage of using the low-cost sensors for establishment of BIM in thermal performance of different structures has already proven. Along with the undertaken studies, it has to be mentioned that the accuracy of the low-cost sensors is a decisive parameter in reliability of the BIM. Therefore, in section 2 of this article, a comprehensive information about the Arduino mechanism, types of smart connections and types of low-cost sensors will be presented. In the third section a detail explanation related to the performed experiments in terms of

performance of low-cost sensors DHT22 will be explained.

2. Open source hardware/software

Arduino UNO is an open source software/hardware for making interactive electronic objects. The physical programable part is of 6.8 cm * 5.3 cm board which has 14 digital input/output pins, 6 analog inputs, 5 power pins (VIN, 5V, 3.3V and GND) with different performances, a 16 MHz crystal oscillator, a USB connection for compiling the data as well as using power supplied form the laptop/computer, a DC power jack (7 − 12V), a reset button for restarting the program/Arduino from the beginning and some small parts [8]. For talking to the sensors through Arduino as well as programing the board through compiling the sketches the open- source Arduino Integrated Development Environment (IDE) software has been presented [9]. This cross-platform application has written in Java, C and C^{++} and is compatible with all Windows, MacOS and Linux. The Arduino environment is extendable by utilizing the libraries. These libraries have written in C/ C^{++} and they increase functionality of the sketches for working with hardware as well as manipulating data. One of the main capabilities of microcontroller is to read sensors and capture the values. In other words, it can be express that sensors are sort of objects, capable of converting physical quantity (like temperature or humidity) into an electrical quantity. For measuring different parameters through Arduino various types of sensors exist. For instance, temperature, motion, humidity, vibration, displacement, pressure and etc. these measurements might be done for several purposes such as smartening systems of metering, retail, logistic, agriculture and security. For the connection of a sensor to the Arduino and observing the measured parameters, sensor's library which defines a canonical set of predefined sensors and control ability, should be

used. The Arduino's sensors are categorized as digitals and analogs. Analog sensors observe the external changes such as temperature and humidity variations and yield analog voltage that represents the measured parameter. For instance, 2V might mean 23 degrees Fahrenheit. Normally this output voltage is between 0 to 5V. Analog signals might be influenced by the ambient noise which leads to produce errors in the output signals. However, the digital sensors generate discrete values like 0 and 1 which are so called digital/binary signals. They have lower range of calculation than the analog ones. Therefore, the analog sensors are more appropriate for wide range of measurements. As far as the analog outputs are liable to change rapidly and unpredictably, digital sensors are preferred over the analog ones.

3. Development of measurement system

Temperature and humidity are one of the decisive factors measured in many projects. In order to evaluate the accuracy of the low-cost temperature sensors, it was decided to stablish an Arduino-based thermal controlling system. This system is going to measure variation of the temperature in an oven located in Universidad de Castilla-La Mancha (UCLM). The Arduino-based thermal measurement system is depicted in Fig.1.
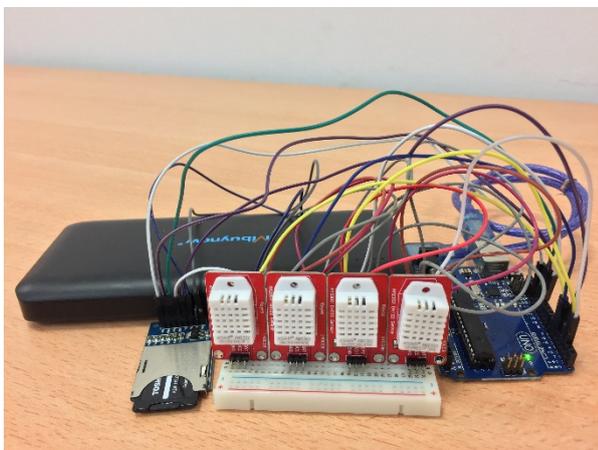

Figure 1. The Arduino-based measurement system.

3.1 Utilized instruments

Fig. 2 shows all the used particles for establishment of this measurement system Arduino UNO, DHT22 sensor, breadboard and SD Card/Reader. The proposed system is based on the open source Arduino UNO platform and low-cost temperature/humidity sensor DHT22. The operating temperature of this sensor is between -40° C to 80° C with accuracy of 0.5° C. It is also capable of measuring humidity from 0-100% with resolution of 0.01 and accuracy of 2-5% RH. DHT22 sensor was chosen since it is one of the most employed and common low-cost humidity and temperature sensors in the engineering and environmental projects. The communication system of the sensor is a custom protocol which use a single wire/bus communication. As illustrated in the Fig. 1, four DHT22 sensors have installed on the small size breadboard hooked up to the Arduino through digital pins numbers 2, 3, 5 and 6 and the power supply (5V) ports of Arduino. [10].
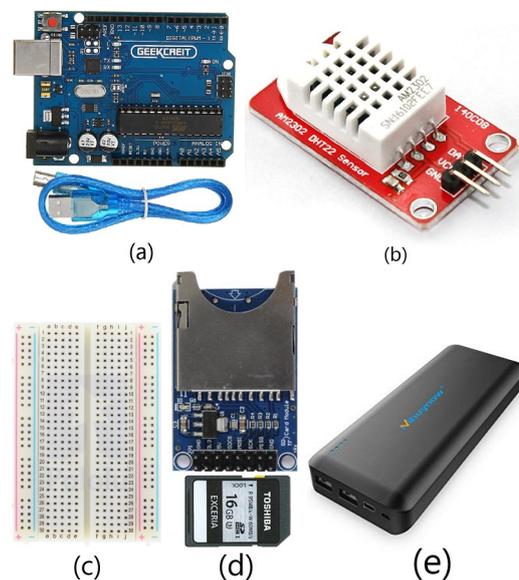

Fig.2. Arduino UNO (a), DHT22 Sensor (b), Breadboard (c), SD Card/Reader (d) and Power bank.

3.2 Comparative results of the sensors.

To estimate the responses of DHT22 sensor as well as their precision, variation of the

temperature versus time related to the 4 sensors shown in the Fig.3. The sensors adjusted to record the temperature with frequency of 2 seconds. All of them have been registered to measure the temperature inside an oven in the laboratory of Universidad de Castilla-La Mancha (UCLM). Model of the oven is SELECTA-2001244, Capable of changing temperature from 10° C to 250° C with precision of 2% and resolution of 1° C. In order to figure out the precision of the sensors, the oven adjusted to reach to the temperature of 30° C and keep working for period of time. As shown in the Fig. 3, variation of the temperature has been divided to two parts. The first part shows variation of the temperature for reaching to the adjusted temperature and the second part depicts behavior of the sensors at the fixed temperature of 30° C. In the second part the sensor number 1, number 2, number 3 and number 4 are showing constantly the temperature of 29.6° C, 29.4° C, 29.4° C and 29.6° C respectively. It has to be mentioned that in our measurements not only we are facing with error of the sensors, but also the oven has its own range of error, 2%, as mentioned in the above.
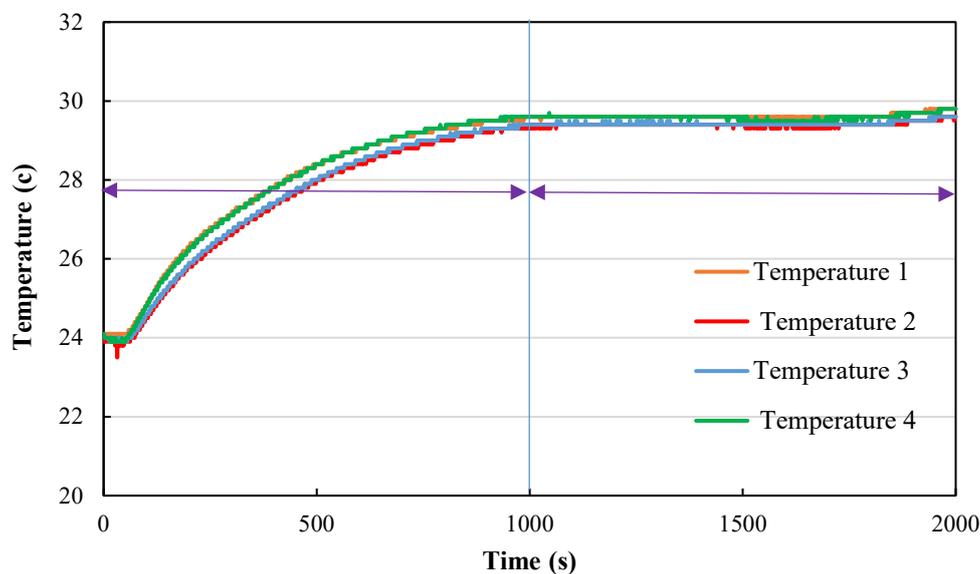

Figure 3. Variation of the temperature related to the four DHT22 sensor.

By this graph it is clearly visible that the accuracy tolerance of the temperature sensor DHT22 is around 0.5° C. The obtained range of accuracy is almost as equal as the one indicated by the manufacturer in the DHT22 datasheet, 0.5° C [11]. Low cost environmental sensors are so useful for determining the thermal parameters of buildings [12]. Moreover, they are applicable for determining characteristic of structures and inferring variation humidity and temperature of concrete during the construction procedure [13].

In order to have better recognition of the sensors' accuracy it is better to have a statistic view on the obtained results. In statistic standard deviation is defined as amount of dispersion of a data set. In this criterion, a low range of standard deviation shows that the values are tending to get close to the average/mean of the dataset however, the high range of that demonstrate that the set of data are dispersed and has a wider range. This index is defined as the square root of variance. To do so, in the first step the mean value must be calculated by adding all the values and dividing them by the number of data points. In the second step, the variance of each data point must be derived by subtracting the value

of each point from mean. Then the resulting values is squared and have to be summed. The obtained result will be divided by the number of data points minus one. As the last step of the calculation, the square root of the second step (variance) ought to be taken to have the standard deviation. Formula number 1 shows calculation of the standard deviation. Which x_i is value of the ith point in the data set, μ is mean value of the data set and N is the number of the data points. It can be seen from Fig. 4 that the derived standard deviation related to the four sensors vary from 0.04 to 0.13 which shows a good performance trend. These 1000 measured point are belong to the second part of the

measurement when the homogenous temperature of 30° C starts in the oven.

$$\sigma = \sqrt{\frac{1}{N}\sum_{1}^{N}(x_i - \mu)^2} \qquad (1)$$

The same calculations have been done for humidity measurement of the sensor DHT22. Fig. 5 illustrates the derived variation of humidity from the four installed sensors. The graph has been divided to 3 parts. The first short period with small fluctuation relates to the time that the measurement system was still plugged in the laptop to become sure about the system functionality [14].
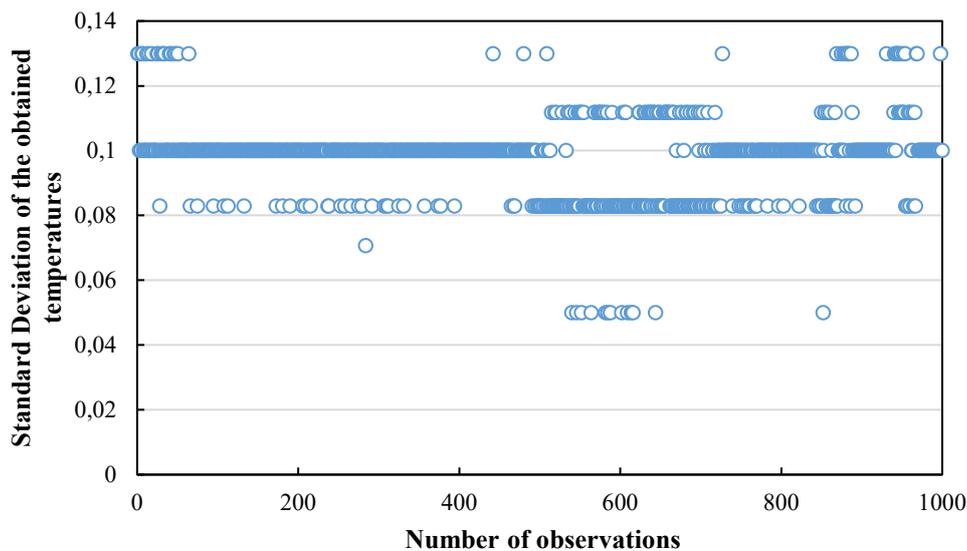

Figure 4. Variation of the standard deviation related to the 1000 measurements of temperature.
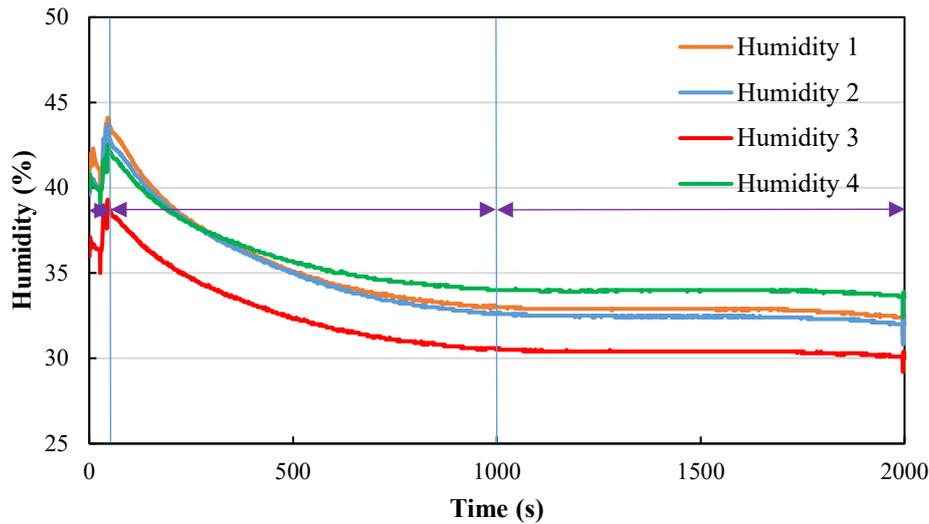
Figure 5. Variation of the humidity related to the four DHT22 sensor.

Afterwards by connecting Arduino to the power bank and putting them in the oven, the second part of the graph was obtained. This part belongs to change of temperature from 24° C to 30° C. From the second 1000th up to the end, is illustration of the fixed temperature on 30° C. In the last period different sensors show the humidity from the range of 30.4% (sensor number 3) to 34% (sensor number 4). The minimum range of differences exist between the sensors number 1 and 2 (0%≤dif. ≤4.5%). The maximum range of differences exist between the sensors number 3 and 4 (7.3%≤dif. ≤12.3%). Fig. 6 depicts variation of the differences between sensors number 1-2 and 3-4. Fig. 7 shows dispersion of standard deviation (in the case humidity) calculated for the four sensors by 1000 measurements at the third step of Figure 5. Standard deviation is always positive number. Majority of the observations were extended above 1.25 close to 1.3 (1.25≤Standard deviation ≤1.3). A low range of standard deviation same as Fig. 4 (related to temperature) shows that the observations tend to be close to the average temperature, however the higher one presents

(Fig. 7) the wider range of observations discrepancy.

In many monitoring projects, engineers consider only a single measurement of a parameter for the purpose of the monitoring. But there is always a basic monitoring question: "if we only perform one measurement, how do we know if it is accurate?" this question remains a gap in all monitoring projects such as the thermal one. This question comes from various source of error such as human error and instrument one.

Due to high cost of measurement devices, increase of monitoring at a fixed situation is almost impossible for all the engineers. Some of thermal low-cost sensors have better accuracy than popular metering devices in the market such as REED R6001 (with accuracy of 0.8 °C and Price of 103 Euros). Taking the advantage of these kits it can be said that conducting data collection using the proposed thermal monitoring system is more rational, more accurate an economical than the industrial devices in the market. Since at the same time not only we are paying less the conventional methods, but also, we are conducting spatial thermal monitoring with more data.
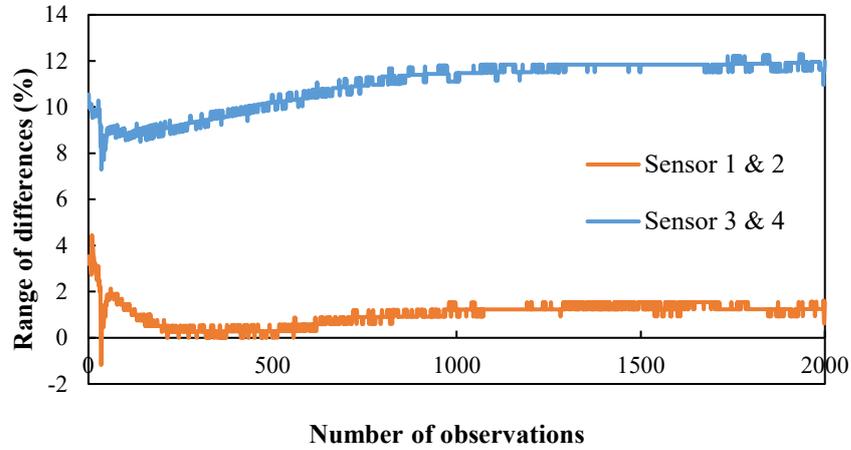
Behnam Mobaraki, Seyedmilad Komarizadehasl, Francisco Javier Castilla Pascual and Jose Antonio Lozano Galan / VIII ACHE CONGRESS–

SANTANDER 2020 6

Fig. 6. Variations of differences between sensors 1 & 2 and 3 & 4.
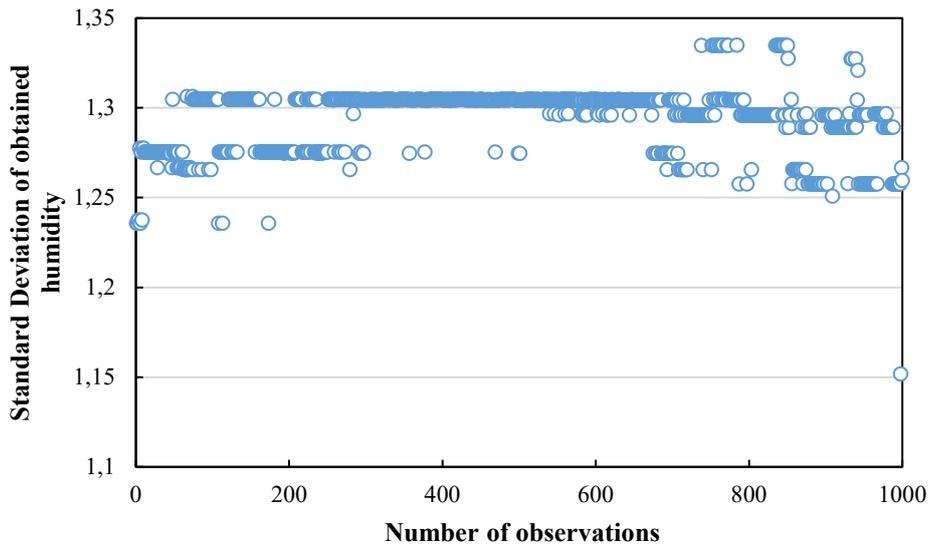

Figure 7. Variation of the standard deviation related to the 1000 measurements of humidity.

4. Conclusion

Low-cost environmental sensors are so practical in building rehabilitation projects for enhancing thermal resistance of buildings. Evaluation the accuracy of the low-cost temperature/humidity sensors through an Arduino-based system has been done for the

environment sensor DHT22. Four sensors have hooked up to the digital ports 2, 3, 4 and 5 of the Arduino and variation of temperature and humidity related to the oven SELECTA were presented in this article. Lower range of standard deviation acquired for the temperature data set ($0.04 \leq$Standard deviation ≤ 0.13) rather than humidity ($1.15 \leq$Standard deviation ≤ 1.33). Which means that the sensor DHT22 is more

Behnam Mobaraki, Seyedmilad Komarizadehasl, Francisco Javier Castilla Pascual and Jose Antonio Lozano Galan / VIII ACHE CONGRESS–

SANTANDER 2020   7

accurate in terms of measuring temperature rather than humidity. From the obtained results it is clearly visible that the range of accuracy or in the other word the precision of the temperature sensor DHT22 is around 0.5° C which is almost equal to the one mentioned in the DHT22 datasheet, 0.5° C.

Reference

[1] N. Barroca, L.M. Borges, F.J. Velez, F. Monteiro, M. Gorski, and C.J. Gomez, Wireless sensor networks for temperature and humidity monitoring within concrete structures. Construction and Building Material. 2013. 40, 1156-1166.

[2] Y. Wang, J. Li, H. Jiang, Q. Zhang, J. Jiang, and P. Biswas, Labratory evaluation and calibration of three low-cost particle sensors for particulate matter measurements. Aerosol science and technology. 2015. 49, 1063-1077.

[3] O. Bamodu, L. Xia, and L. Tang, An indoor invironment monitoring system using low-cost sensor network. Procedia. 2017. 141, 606-666.

[4] M. Marzouk, and A. Abdelaty, Monitoring termal confort in subways using building information modeling. Energy and Buildings. 2014. 84, 252-257.

[5] J.B. kim, W. Jeong, M.J. Clayton, J.S. Habrel, and W. Yan, Developing a physical BIM library for building termal energy simulation. Automation in construction. 2015. 50, 16-28.

[6] L.G. Garcia, and B. Kamsu-Foguem, BIM-oriented data mining for termal performance of prefabricated buildings, Ecological Informatics. 2019. 51, 61-72

[7] B. Mobaraki. and M. Vaghefi. Numerical study of the depth and cross-sectional shape of tunnel under surface explosion. Tunnelling and underground space technology. 2015. 47, 114-122

[8] A.M. Garin, J.A. Millan-Garcia. A. Bariri. J. Millan-Medel and J.M. Lizzaraga. Environmental monitoring system based on an open source platform and the internet of things for a building energy retrofit. Automation in Construction. 2018. 87, 201-214.

[9] Philips Semiconductors, Arduino datasheet.

[10] The Sensor Company, SHT21 datasheet.

[11] M.S. Zarnik, and F.N.G. Papa, Thermal phenomena in LTCC sensor structures. Sensors and Actuators A: Physical. 2019. 290, 198-206.

[12] B. Mobaraki. and M. Vaghefi. Investigation of dynamic behavior of concrete bridge columns under surface blasting, Sharif Journal of Civil Engineering. 2018. 133-141.

[13] J. A. Lozano-Galant, M. Nogal, E. Castillo, and J. Turmo, "Application of observability techniques to structural system identification," Comput. Civ. Infrastruct. Eng. 2013. 434–450.

[14] B. Mobaraki. and M. Vaghefi. Effect of the soil type on the dynamic response of a tunnel under surface detonation", Combust. Explos. Shock Waves, 2016. 52(3), 363–370.