Turkish Journal of Electromechanics and Energy
ISSN: 2547-975X
Vol:6, No:1, Page 12-17 (2021)
https://www.scienceliterature.com

Development of a solar-based temperature and relative humidity data logger

A. Y. Bayhan[1], C. Turhan[1,*]

[1]Energy Systems Engineering Department, Atılım University, Ankara, Turkey

ARTICLE INFO

***Article Type*:**
Special Issue Article[©]

Article History:
Received: 14 April 2021
Revised: 14 May 2021
Accepted: 25 May 2021
Published: 30 June 2021

Editor of the Article:
M. E. Şahin

Keywords:
Thermal comfort
Data loggers
Measurements
Renewable energy
Temperature
Relative humidity

ABSTRACT

Data loggers measure indoor air parameters such as temperature and relative humidity by using several sensors in buildings. These parameters are the most crucial factor in calibrating energy simulation programs. However, data loggers are very expensive and require hard-to-understand hardware to store data. In addition, these devices use standard lithium batteries to supply the energy of sensors. However, some of the data can be missed due to the low battery life of the data loggers. Furthermore, tracking the measured data is very difficult since they require additional software, which is confusing for engineers and architects. This study aims to develop a solar power-based low-cost data logger and record the measured data as an excel file into the micro SD card. For hardware purposes, a temperature and humidity sensor, an Arduino microcontroller card, a micro SD card module, a solar panel, and a battery unit are used while software codes are written to generate permanent data. The low-cost temperature and relative humidity data logger prototype is manufactured and tested in a case building at Atılım University in Ankara/Turkey. Then, the developed data logger is compared with the HOBO-U12 data logger during four days. The results show that the cost of the data logger can be decreased by approximately 82%. In comparison, the accuracy of the data is 97% and 96% for temperature and relative humidity, respectively, compared to the commercial data logger.

Cite this article: A. Y. Bayhan, C. Turhan, "Development of a solar-based temperature and relative humidity data logger," *Turkish Journal of Electromechanics & Energy*, 6(1), pp.12-17, 2021.

1. INTRODUCTION

Buildings are responsible for 40% and 32% of total energy consumption in Europe and Turkey, respectively [1]. Considering developing countries, such as Turkey, have limited energy resources, decreasing the energy consumption of the buildings becomes a vital issue. On the other hand, the environmental impact of carbon dioxide (CO_2) emissions of the building sector increase in even developed countries. It is worth noting that buildings require to consume a certain amount of energy according to heating and cooling loads, zone, location, and type of the building [2]. However, the building sector also represents 50% of energy-saving potential energy consumption [3]. Here, energy-efficient Heating, Ventilating, and Air-Conditioning (HVAC) systems, well-insulating building elements such as walls and windows, and occupant-centric control systems are significant examples to decrease the energy consumption of the building [4, 5]. However, as a first step, it is necessary to determine the energy consumption of the building to apply these retrofits to the building. Considering large and complex constructions, in situ measurement of energy consumption of the buildings is very complicating since energy consumption is highly affected by multi-parameters that are interrelated [6]. In this context, dynamic building energy simulation programs (DBESP) are one of the most efficient tools to estimate the total energy consumption and, therefore, foresee early inaccuracies in the construction [7, 8]. DBESPs provide simulation predictions that match closely with the actual energy consumption of the buildings [9]. However, the DBESP model of the building must be calibrated by using monitored data to get more accurate results [10]. For calibration, the case building's annual outdoor and indoor air temperature and relative humidity values are required.

In this case, data loggers are used to accurately record the temperature and humidity data of the building on an annual basis.

[©]*Initial version of this article was presented in the 5th International Anatolian Energy Symposium (5th AES), which was held on March 24-26, 2021, in Trabzon, TURKEY; and was subjected to a peer-review process before its publications.*

* Corresponding author e-mail: cihan.turhan@atilim.edu.tr

In other words, data loggers form the accuracy of the DBESPs [11]. Here, it is worth reminding that data loggers are essential for these programs and for occupants who want to monitor the temperature and humidity of their buildings. Data loggers use several sensors and communication systems between sensors and the central server [12]. Commercially, there exist many temperatures and relative humidity data loggers in the building market. However, their prices are pretty high. In addition, many producers prefer to use their user interfaces which are difficult to understand by the occupants. These limitations force many researchers in various fields to develop their data loggers [13]. For instance, Frisby et al. [14] developed a unique temperature monitoring device to assess pig meat quality. The system consisted of two temperature probes attached to a Radio-Frequency (RF) data logging unit, which transmits temperature data to the RF base station with the help of low power radio frequency communications.

Similarly, Sidik et al. [15] developed a novel Arduino-based data logger to measure temperature and humidity for meteorology and geoscience fields. The authors used a mobile data logger, a microcontroller, a Global Positioning System (GPS) module, Light Emitting Diodes (LEDs), a Liquid Crystal Display (LCD) module, and an SD card module. To verify the operation of the temperature and humidity data logger, a test was conducted by comparing the temperature and humidity data from the prototype device with a commercial certificated device. The authors concluded that the developed data logger measured temperature with an error of 3.1ºC.

On the other hand, limited studies used developed data loggers in the building sector. For instance, Ali et al. [16] developed an inexpensive open-source platform for logging building environmental data. The novel data logger included air temperature, relative humidity, occupancy, light, and CO_2 sensors. A Negative Temperature Coefficient (NTC) thermistor and Sensirion SHT15-type digital humidity sensor were chosen for temperature and relative humidity measurements. The authors indicated that researchers could save approximately 50% of the total cost by developing their data loggers. However, there exist limited studies on the development of low-cost and energy-efficient data loggers in the literature.

To this aim, the purpose of this study is to develop a solar power-based low-cost data logger and save the monitored data into the micro SD card as an excel file. The diversity of this data logger is a chargeable battery since it uses renewable energy sources to charge a battery. A test office room located in Atılım University/Ankara-Turkey is selected as a case study for testing the developed data logger. A short measurement campaign of four days during the winter season is investigated to compare and calibrate the developed data logger on a 5-minutes interval basis.

2. METHODS

The methodology of the study lies in two main sections. The first section gives the development of solar power-based low-cost, energy-efficient temperature, and relative humidity (T&RH) data loggers. In contrast, the developed data logger is compared with a HOBO-U12 T&RH data logger in the second section (Figure 1).

2.1. Development of Data Logger

The proposed data logger consists of a microcontroller, a T&RH sensor, an LCD, a potentiometer, a micro SD card, a resistor, and two solar panels. Arduino Uno, which uses Atmega 2560 base controller, is used to execute logical operations of the data logger [17]. The controller has 14 digital input/output pins (6 of them can be used as PWM outputs), six analogue inputs, 16Mhz crystal, a USB socket, a power socket, an ICSP connector, and a reset button. The developed data logger distinguishes it from other commercial products with the chargeable battery since it uses renewable energy sources. The data logger provides its energy from two 3.7 V Li-Ion batteries which can charge itself permanently with two 5.5 V monocrystalline solar panels. The 2S Li-Ion Battery Charge Circuit is used to charge 2S batteries operating between 4.2V - 3.6V x 2 with the TP4056 linear charging integrated on it as a battery charging unit. The data logger measures T&RH via a DHT22-type sensor which provides a calibrated digital signal output [18, 19]. In addition, a Micro SD card is used to store measured data in an Excel file. The data logger also displays the measured T&RH values on an LCD screen which has 2x16 character dimensions. It is worth noting that a trimmer is also added to adjust the backlight of the LCD. The complete list of components of the data logger and their specifications are depicted in Table 1.

Fig. 1. The methodology of the study.

Table 1. Specifications of all components of the developed data logger.

Components	*Picture*	*Properties*
Arduino Microcontroller Card		Operating voltage:5 V Input Voltage:7-12V
2x16 LCD Display		Operating voltage:+ 5V Operating temperature: -20 - +70°C
DHT22		Resolution:0.1ºC Humidity measurement accuracy:± 2% RH Temperature measurement accuracy: ±0.5
5.5 V Solar Panel		Material: Monocrystalline Voltage: 5.5V Current:100mA Power:0.6 W
Battery Charging Circuit		Overload Voltage Range: 4.25-4.35v ± 0.05v Over-discharge Voltage Range: 2.3-3.0v ± 0.05v Operating Current: 3A Operating Temperature: -40 ~ + 50 ℃
RTC and SD Cart Data Logger Shield		DS1307 RTC integrated CD4050 Micro SD card IC driver Automatically control 3.3V Compatible with Arduino UNO R3
Potentiometer		Resistance range: 0 ~ 10,000 ohm
Micro SD Card		Capacity: 2 GB
Li-Ion Battery		Voltage: 3.6V-4.2V Capacity: 2600mAh Nominal Voltage: 3.63V Charging Method: CC-CV Weight: 48g Size: 65mm x 18mm

Figure 2 depicts the circuit connection diagram of the developed data logger, and Figure 3 shows an exemplary screenshot of data logger programming. The data logger uses a C-based programming language to adjust according to the desired specifications easily. After wiring and connections, the data logger is packed in a storage box.

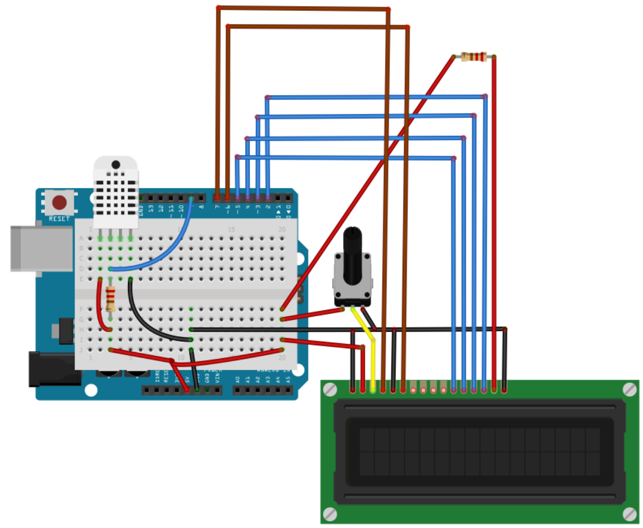
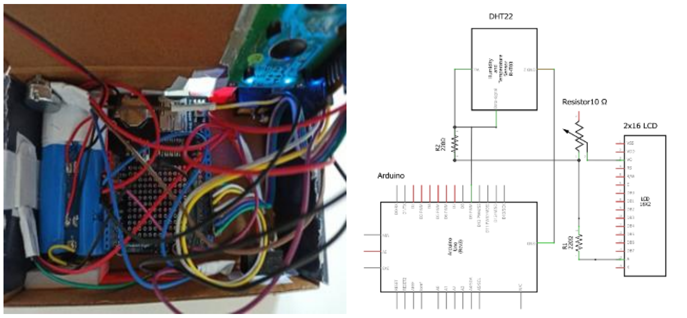


Fig. 2. Circuit connection diagram.

```
// Create a file to store the data
File myFile;
//RTC
RTC_D51307 rtc;
void setup ( ) {
//initializing the DHT sensor
dht.begin ( );
// initializing the serial monitör
serial.begin (9600);
//setup for the RTC
While (!Serial);//for Micro
If (!rtc.begin ( )) {
Serial.print In(couldn't find RTC");
while (1);
}
else {
//following line sets the RTC to the date and time this sketch is compiled
rtc.adjust (DateTime (f(_DATE_), (_TIME_)));
```

Fig. 3. Screenshot of a part of the data logger programming.

The produced storage box is 158 gr with a total dimension of 90 x 51 x 38 mm. The T&RH sensor is placed inside the box since the sensor is not affected by the sunlight, while solar panels are located on the lateral surface in Figure 4. Finally, it is worth noting that the developed data logger can be placed on walls with the help of a bracket.



(a) (b)

Fig. 4. a) The inside, b) The electrical circuit of the developed data logger.

2.2. Comparison of Data Loggers

A measurement campaign is designed to evaluate the accuracy of the developed data logger. The measurements are taken between the 28th and 31st of January in an office room located at Atılım University Campus, Ankara, Turkey (at 32.52ºE 39.56ºN). The dimension of the office room is 5 x 3 x 2.8 m with a tree internal and an external wall facing south direction as seen in Figure 5. On the external wall, a 6.7 m^2 window exists, while the window to wall ratio of the south facade is 3.6. The developed data logger is compared with a well-known calibrated T&RH data logger, a commonly used sensor in dynamic energy simulation tools. The data are taken at 5-minutes intervals at the same time with a commercial data logger. Then, measured data are compared with a linear calibration curve and assessed with Pearson's correlation coefficient (r), which is calculated according to Equation 1 [20].

$$r = \frac{\sum_i^p (t_i - \bar{t}) - (o_i - \bar{o})}{\sqrt{\sum_i^p (t_i - \bar{t})^2 * \sqrt{\sum_i^p (o_i - \bar{o})^2}}} \quad (1)$$

Here, t_i is the data of the developed data logger, $\bar{t}$ and $\bar{o}$ are averages of the data, o_i specifies the data of the commercial data logger, and p represents the number of input-output pairs of i^{th} data. Finally, the cost analysis of two data loggers is conducted.

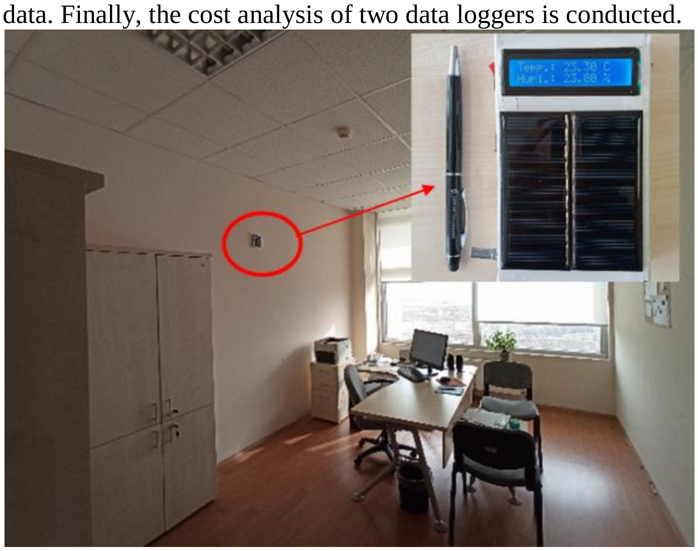


Fig. 5. Case office room used for the study.

3. RESULTS AND DISCUSSIONS

A total of 656 T&RH data were recorded between the 28th of January and 31th of January 2020 in the case office room. The results of the developed data logger were then compared with a HOBO-U12 data logger. The measurements were carried out every 5 mins during the measurement campaign. Figure 6 depicts the comparison of the measured temperature values for both developed and commercial T&RH data loggers. The figure indicates that the developed data logger measured T values with an accuracy of r =97.4% compared to the commercial one.

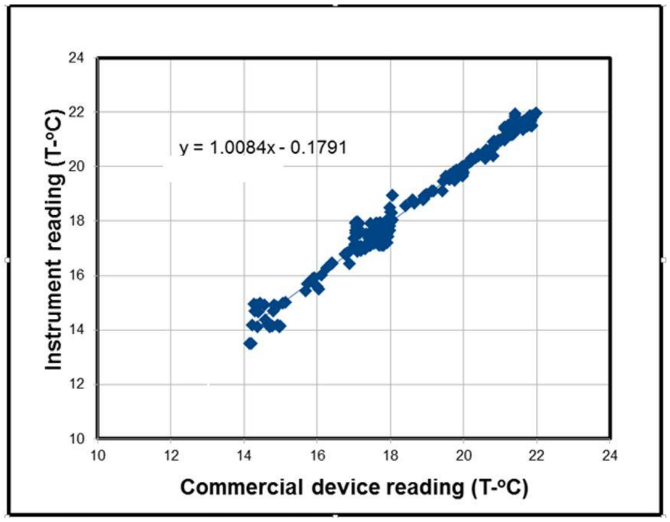


Fig. 6. Comparison of the temperature measurements.

Figure 7 represents the distribution of the residuals for temperature measurements. It is worth noting that the developed data logger under-measured temperature values below 18°C while over-measured above 22°C. The reason could be the design of the storage box of the data logger. In commercial data loggers, the temperature sensor is located inside the box. However, to avoid internal heat gains from electronic devices such as the microcontroller used in the data logger, the temperature sensor is located on the storage box. This purpose means that the developed data logger was highly affected by sudden temperature changes.

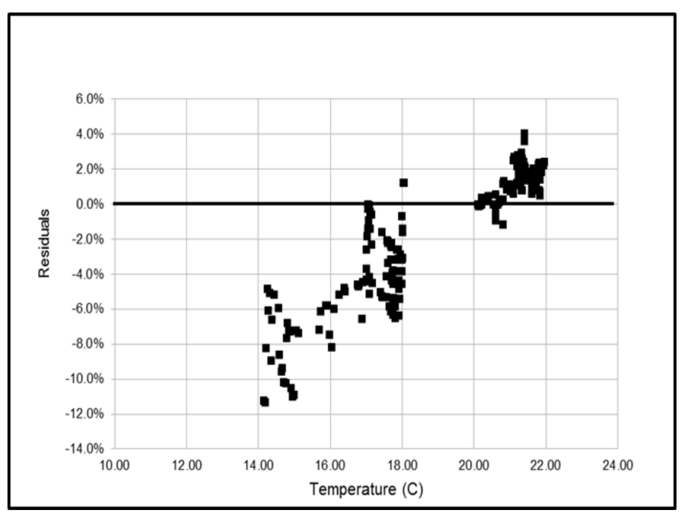


Fig. 7. Residual distribution for temperature measurements.

Figures 8 and 9 show the comparison of the RH measurements and the distribution of residuals, respectively. The figures indicate that the developed data logger was accomplished since the data fit with the commercial data logger's data. This result is also supported by the fact that the r value was 96.5%. In addition, a strong linear trend in Figure 8 indicated the normality of the errors. However, the same problem with temperature measurements can be drawn here again for RH measurements.

When developing the solar power-based data logger can be taken into account, the effect of design factors should also be considered. The commercial products combine optimum design parameters with suitable material properties. However, this case is not handy for developing a new prototype. For this reason, the accuracy and response time of the device could increase upwards after serial manufacturing. Finally, the cost of the components of the developed data logger was shown in Table 2. The developed data logger merely costs 27.1$ while the commercial data logger is 150$ [21]. In addition, an extra payment is also required for launching the device and reading data from a commercial data logger, which costs an additional $100 [22]. The researchers can save 82% of the total price by developing their data loggers. PV panels are the most expensive parts (cost approximately 6$) of the developed data logger. However, considering a battery life of 8 months for commercial products, they supply a chargeable battery to the device.

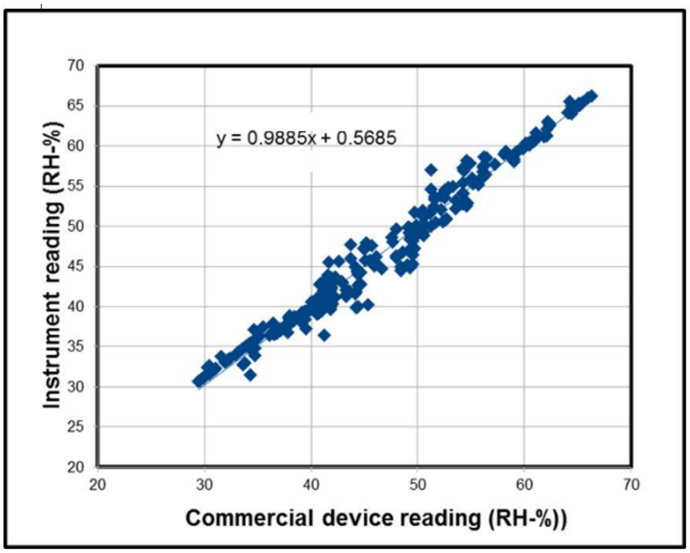


Fig. 8. Comparison of the RH measurements.

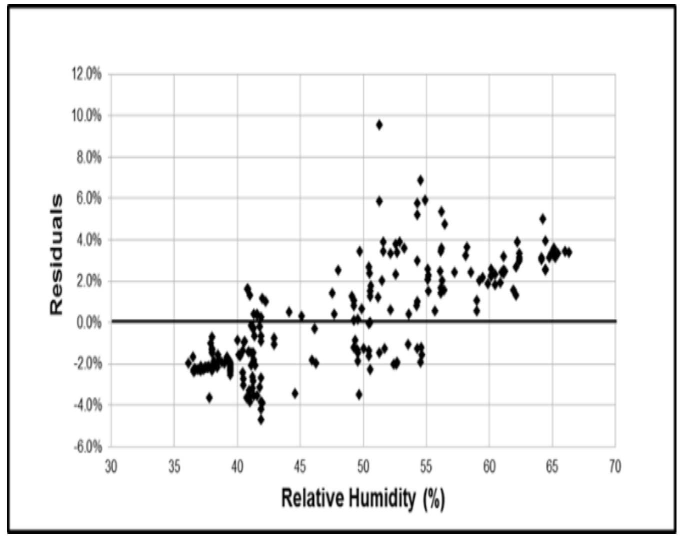


Fig. 9. Residuals for RH measurements.

Table 2. Cost analysis of developed data logger.

Component	*Piece*	*Unit price*	*Total price*
Arduino Uno R3 Microcontroller Card	1	5.9 $	5.9 $
RTC and Micro SD Card Data Logger Shield	1	3.5 $	3.5 $
2x16 LCD Display	1	1.6 $	1.6 $
Potentiometer	1	0.3 $	0.3 $
DHT22	1	3.8 $	3.8 $
2 Gb Micro SD Card	1	1.5 $	1.5 $
5.5 V-0.6 W Solar Panel	2	3.2 $	6.4 $
Rechargeable Li-Ion Battery 3.7 V	2	1.5 $	3.0 $
2S Battery Charging Circuit	1	1.1 $	1.1 $
TOTAL PRICE			*27.1 $*

4. CONCLUSIONS

Temperature and relative humidity data loggers are now very popular in many application areas, from basic home applications to dynamic building energy simulation programs. However, these data loggers are very expensive and not user-friendly due to the limitations and complexity of the user interfaces. To this aim, this study proposed to design a solar power-based low-cost, energy-efficient, and reliable temperature and relative humidity data logger. The developed data logger included a microcontroller, a T&RH sensor, an LCD, a potentiometer, a micro SD card, a resistor, and two solar panels. The developed data logger was then compared with a HOBO-U12 data logger. The results showed that researchers could save approximately 82% of the total price with the accuracy of the results by r of 97% and 96% for temperature and relative humidity, respectively.

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Biographies

Ahmet Yaser Bayhan was born on September 1996 in Ankara, Turkey. In 2020, he graduated from Atılım University Department of Energy Systems Engineering. He worked on temperature and relative humidity data loggers in his graduation project.

E-mail: bayhan.ahmetyaser@gmail.com

Cihan Turhan was born on May 03, 1985 in Akhisar/Manisa, Turkey. After graduating with the PhD, Department of Mechanical Engineering Program at Izmir Institute of Technology, he works as an Assistant Professor in the Energy Systems Engineering Department of the Atılım University since 2019. Dr Turhan currently researches Building Energy Efficiency, Indoor and Outdoor Thermal Comfort, and Artificial Intelligence in Smart Buildings. Dr Turhan has many ongoing projects, published articles, and conference papers on building energy efficiency, and he is a reviewer of many international journals. Moreover, Dr Cihan Turhan is an associate member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

E-mail: cihan.turhan@atilim.edu.tr