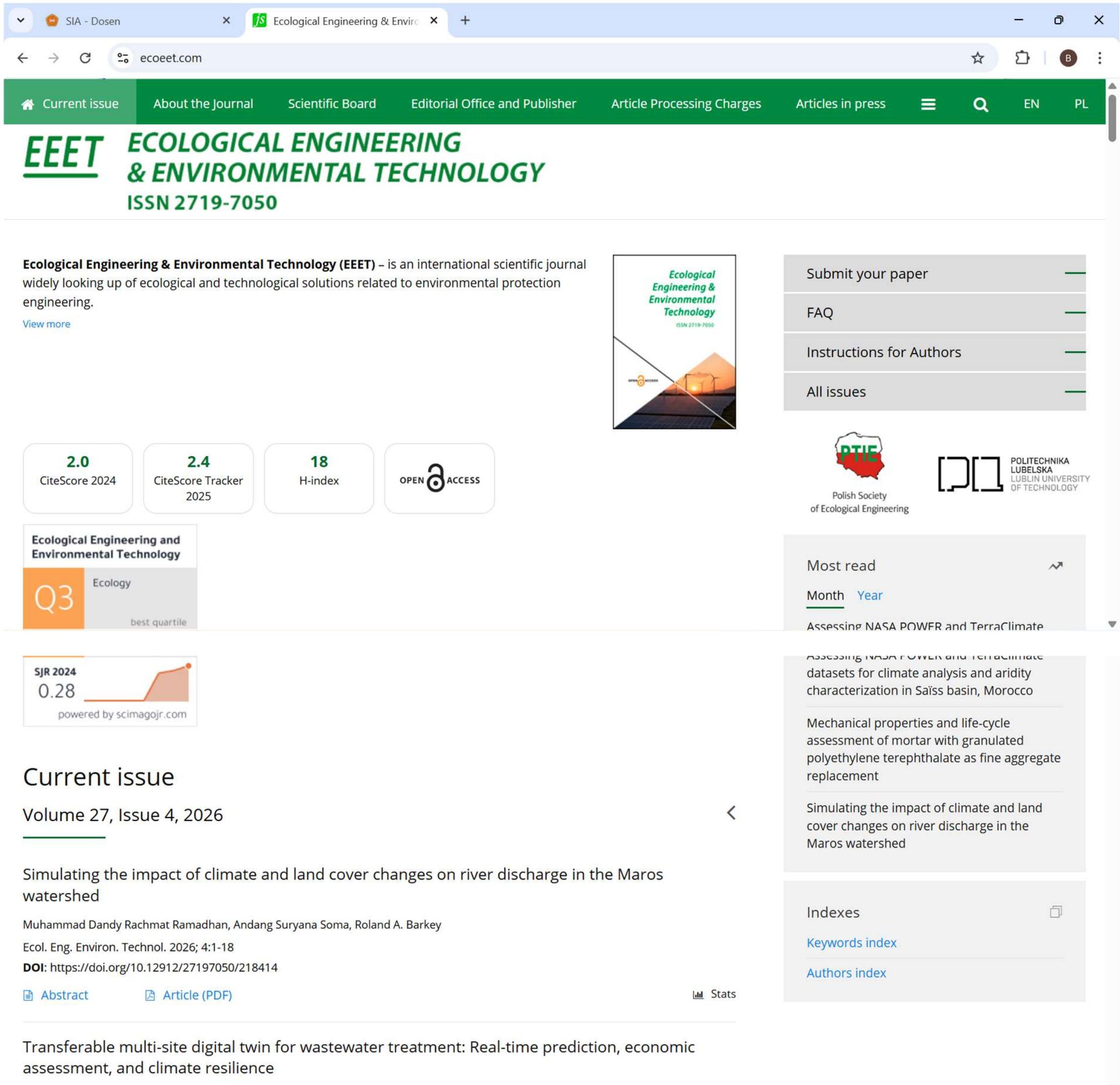
Halaman depan

https://www.ecoeet.com/



SIA - Dosen | Ecological Engineering & Enviro

ecoeet.com

Current issue | About the Journal | Scientific Board | Editorial Office and Publisher | Article Processing Charges | Articles in press | EN | PL

EET

ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

ISSN 2719-7050

Ecological Engineering & Environmental Technology (EEET) – is an international scientific journal widely looking up of ecological and technological solutions related to environmental protection engineering.

View more

Submit your paper

FAQ

Instructions for Authors

All issues

2.0 CiteScore 2024

2.4 CiteScore Tracker 2025

18 H-index

OPEN ACCESS

Polish Society of Ecological Engineering

POLITECHNIKA LUBELSKA LUBLIN UNIVERSITY OF TECHNOLOGY

Ecological Engineering and Environmental Technology

Q3 Ecology

best quartile

SJR 2024 0.28

powered by scimagojr.com

Most read

Month Year

Assessing NASA POWER and TerraClimate datasets for climate analysis and aridity characterization in Saïss basin, Morocco

Mechanical properties and life-cycle assessment of mortar with granulated polyethylene terephthalate as fine aggregate replacement

Simulating the impact of climate and land cover changes on river discharge in the Maros watershed

Current issue

Volume 27, Issue 4, 2026

Simulating the impact of climate and land cover changes on river discharge in the Maros watershed

Muhammad Dandy Rachmat Ramadhan, Andang Suryana Soma, Roland A. Barkey

Ecol. Eng. Environ. Technol. 2026; 4:1-18

DOI: https://doi.org/10.12912/27197050/218414

Abstract | Article (PDF) | Stats

Indexes

Keywords index

Authors index

Transferable multi-site digital twin for wastewater treatment: Real-time prediction, economic assessment, and climate resilience

Bernadeta Wuri Harini, Rusdi Sambada, Budi Sugiharto, Andreas Prasetyadi

Ecol. Eng. Environ. Technol. 2026; 4:107-117

DOI: https://doi.org/10.12912/27197050/218493

https://www.ecoeet.com/pdf-218493-137681?filename=Design-of-a-relative-humi.pdf

Editorial Office and Publisher

Editorial Office
Onyksowa 4/2, 20-582 Lublin, Poland
e-mail: office@ecoeet.com

Publisher
Polish Society of Ecological Engineering – Polskie Towarzystwo Inżynierii Ekologicznej
Nadbystrzycka 40B, 20-618 Lublin, Poland
e-mail: ptie@wngb.pl
website: https://ptie.pl/

EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2026, 27(4), 107–117
https://doi.org/10.12912/27197050/218493
ISSN 2719–7050, License CC-BY 4.0

Received: 2026.02.12
Accepted: 2026.03.16
Published: 2026.04.01

Design of a relative humidity measurement instrument using the psychrometric hygrometry method for sustainable biomass briquette drying

Bernadeta Wuri Harini[1], Rusdi Sambada[2], Budi Sugiharto[2], Andreas Prasetyadi[2*]

[1] Electrical Engineering, Universitas Sanata Dharma, Yogyakarta, Indonesia
[2] Mechanical Engineering, Universitas Sanata Dharma, Yogyakarta, Indonesia
* Corresponding author's e-mail: pras@usd.ac.id

ABSTRACT

In this study, an electronic measuring instrument was designed to measure temperature and relative humidity. The method used to measure relative humidity is the psychrometric hygrometry method. In this method, relative humidity is calculated from measurements of dry-bulb and wet-bulb temperatures. The temperature measured directly with a thermometer is the dry bulb air temperature. The wet bulb temperature is obtained from a thermometer with the tip connected to a water tube via a wick. The wet bulb temperature is affected by airflow. Because the tip of the wet bulb thermometer is connected to the water, the dry bulb temperature is always higher than the wet bulb temperature. The value of these two temperatures is then used to calculate the relative humidity. Therefore, two temperature measuring instruments are required to measure relative humidity. The designed measuring instrument can be used to measure 4 temperature points and 4 relative humidity points. Therefore, the total number of temperature sensors used is 12. In general, the designed measuring instrument is capable of measuring temperature and relative humidity with an error below 5%. The instrument is capable of measuring temperature with an error below 2%. When compared to the calculation of relative humidity with dry-bulb and wet-bulb temperatures measured using a hygrometer, the measuring instrument has an error of 4.29%. When compared to the DHT22 humidity sensor, the error is 4.5%.

Keywords: biomass briquettes, humidity, psychrometric hygrometry, temperature, wet and dry bulb.

INTRODUCTION

One alternative energy source is biomass briquettes made from coconut shell charcoal. The quality of briquettes can be determined by their dryness (Harini et al., 2025; Muda et al., 2026). In the briquette drying process, temperature and relative humidity are key parameters. If these two parameters are not properly monitored, it can result in energy waste, inconsistent product quality, and suboptimal drying performance. This can impact briquette quality.

One method for measuring relative humidity in a briquette drying machine is the Psychrometric Hygrometry method (American Society of Heating, 2001). In this method, relative humidity is calculated from the temperatures obtained from the dry-bulb and wet-bulb. The temperature measured directly with a thermometer is called dry bulb air temperature (Hasan, 2010; Shallcross, 2005). The temperature of the wet bulb is obtained from a thermometer with the tip connected to a water tube via a wick. The wet bulb temperature is affected by airflow. Because the tip of the wet bulb thermometer is connected to the water, the temperature in the dry bulb is always higher than the temperature in the wet bulb. The value of these two temperatures is then used to calculate the relative humidity.

Psychrometric hygrometry has been widely recognized as a robust and reliable method for determining humidity in industrial applications. Nevertheless, the relative humidity is highly sensitive to measurement errors in the dry and wet bulb temperature sensors (Ustymczuk and Giner, 2011). The greater the temperature error in both thermometers, the greater the relative humidity error. Therefore, dry and wet bulb temperature measurements must be calibrated before being used to calculate relative humidity.

The accuracy of the dry-bulb thermometer and the wet-bulb thermometer has been tested to calculate relative humidity using a psychometric chart (Rani, 2022). The results were then compared with the humidity measured with a hygrometer. The study yielded a relative humidity error of 3%. However, the study did not use a measuring instrument to directly measure relative humidity; instead, it only measured temperature with two thermometers. The relative humidity values were then calculated manually. Another study conducted by Chen and Chen (2022) actually sought the wet-bulb temperature value from the dry-bulb temperature and relative humidity based on the psychometric method. This wet-bulb temperature value was obtained by manual calculation.

Several researchers have created relative humidity measuring instruments using various methods. Yang et al. (2006) created Relative Humidity Measurements using an Electrical Conductivity Method. Zhang et al. (2021) made a relative humidity measuring tool using a fiber optic sensor. Fu et al. (2024) also made a relative humidity measuring instrument using an optical fiber. The use of fiber optics in measuring relative humidity requires relatively higher costs.

Most existing studies about psychrometric hygrometry focus on psychrometric analysis for theoretical evaluation. The development of practical psychrometric-based measurement instruments specifically designed for biomass briquette drying machines is currently unavailable. Instrument integration to support energy-efficient and environmentally sustainable briquette drying processes remains underexplored.

As stated above, the relative humidity is calculated using the psychrometric hygrometry method. Unlike the method used by Rani (2022), this measuring instrument will produce an output in the form of relative humidity. The relative humidity calculation in this study uses the equation proposed by Huang et al (2013). This research will investigate whether the designed device can effectively measure relative humidity. The measurement results will be compared with those obtained using a hygrometer. One application of this measuring device is to monitor temperature and humidity, such as in a briquette drying system (Purwadi and Prasetyadi, 2022; Prasetyadi and Kusbandono, 2023). The drying system requires four dry thermometers and four pairs of dry bulb and wet bulb thermometers. This means a total of 12 thermometers are required, consisting of eight dry bulb thermometers and four wet bulb thermometers. This device is designed with tools and materials commonly used in various applications. The temperature is measured using the DS18B20 sensor (Maxim Integrated Products, 2019). This sensor has been widely used to measure temperature in various studies (Suwardono et al., 2024; Satra et al., 2024). The measuring instrument is also equipped with a humidity sensor. This sensor is used to compare the results obtained from the designed humidity meter and the hygrometer. The humidity sensor used for comparison in this study is the DHT22 sensor. This humidity sensor has been widely used in various studies (Sinaga et al., 2026; Yasin et al., 2025; Rajkumar, 2025). However, the two sensors above have not been used for humidity measuring instruments based on the psychrometric hygrometry method. The aim of the study is to create and evaluate a cheap and reliable instrument to measure dynamic humidity applicable to a dehumidifier dryer for a biomass briquette drying machine. Therefore, a temperature and relative humidity (H_r) measuring instrument will be created, which is specifically designed for biomass briquette drying applications.

METHODOLOGY

Calculation of relative humidity using psychrometric hygrometry

In the psychrometric hygrometry method, relative humidity is calculated from the temperature measurement results of the dry-bulb and wet-bulb thermometers. The temperature difference between the temperature at the dry-bulb and the wet-bulb is known as the wet-bulb depression (Hasan, 2010). Wet-bulb depression is a crucial term for determining relative humidity. Relative humidity is the amount of water vapor in the air compared to its full saturation. It means that relative humidity is the ratio between the amount of water vapor in the air and the maximum value that the air can hold at that temperature (Hasan, 2012).

Relative humidity can be calculated using Equation 1 (Huang et al., 2013).

$$H_r = \frac{e_w - A * P * \Delta t}{e_d} \times 100 \quad (1)$$

where: H_r is the relative humidity (%), e_w is the saturation vapor pressure in the wet-bulb temperature (mbar), e_d is the saturation vapor pressure in the dry-bulb temperature (mbar), A is the coefficient of measuring humidity, P is the mean atmospheric pressure (mbar), and Δt is the difference between the temperature in dry-bulb and the wet-bulb (°C).

The temperature difference is calculated using Equation 2.

$$\Delta t = T_d - T_w \quad (2)$$

where: T_d is dry temperature (°C), T_w is wet temperature (°C).

The value of saturation vapor pressure in the wet-bulb temperature (e_w) and in the dry-bulb temperature can be obtained using Equations 3 and 4 (Huang et al., 2013).

$$e_w = 6.112 \times e^{\frac{17.502 \times T_w}{240.97 + T_w}} \quad (3)$$

$$e_d = 6.112 \times e^{\frac{17.502 \times T_d}{240.97 + T_d}} \quad (4)$$

The conversion factor (A) can be calculated by the empirical formula using Equation 5 (Butler et al., 2012).

$$A = 0.00066 \times (1 + 0.00115 \times T_w) \quad (5)$$

The value of mean atmospheric pressure can be calculated using Equation 6 (American Society of Heating, 2001):

$$P = 101.325(1 - 2.25577 \times 10^{-5} Z)^{5.2559}\ kPa$$
$$P = 101.325(1 - 2.25577 \times 10^{-5} Z)^{5.2559} \times 10\ mbar \quad (6)$$

where: Z is altitude (m).

Hardware design

The hardware design of a temperature and relative humidity measuring instrument based on the psychrometric hygrometry method is shown in Figure 1. The measuring instrument consists of:

a) an Arduino Mega microcontroller as the measuring instrument processor;

b) twelve DS18B20 temperature sensors (Maxim Integrated Products, 2019): 4 for room temperature, 4 for dry-bulb, and 4 for wet-bulb;

c) a 20 × 4 I2C LCD (Liquid Crystal Display) to display altitude, pressure (P), temperature, and humidity;

d) a 3 × 4 keypad to input altitude values and select an LCD;

e) four DHT22 (Aosong Electronics Co) to compare humidity values;

f) SDcard shield and RTC (Real Time Clock) to store data and provide time.

The pin connections of the input-output devices to the microcontroller are shown in Table 1. Room temperature measurements were

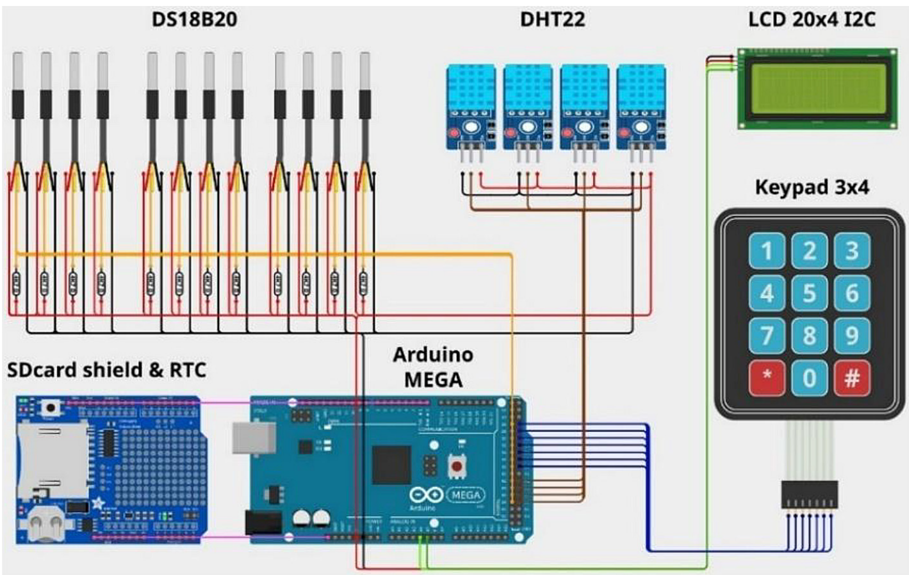


Figure 1. Design of the temperature and relative humidity measurement instrument using the psychrometric hygrometry method

Table 1. Connection of input-output devices to the microcontroller

Arduino Mega PIN	Device/Sensor	Function	Protocol
49	DHT22 - no.1	IO data	OneWire
47	DHT22 - no.2	IO data	OneWire
45	DHT22 - no.3	IO data	OneWire
43	DHT22 - no.4	IO data	OneWire
28	DS18b20 - no.1	IO data	OneWire
32	DS18b20 - no.2	IO data	OneWire
40	DS18b20 - no.3	IO data	OneWire
26	DS18b20 - no.4	IO data	OneWire
30	DS18b20 dry - no.1	IO data	OneWire
34	DS18b20 dry - no.2	IO data	OneWire
46	DS18b20 dry - no.3	IO data	OneWire
36	DS18b20 dry - no.4	IO data	OneWire
42	DS18b20 wet - no.1	IO data	OneWire
44	DS18b20 wet - no.2	IO data	OneWire
48	DS18b20 wet - no.3	IO data	OneWire
38	DS18b20 wet - no.4	IO data	OneWire
10	Sdcard shield	SD CS	SoftSPI
12	Sdcard shield	SD MISO	SoftSPI
11	Sdcard shield	SD MOSI	SoftSPI
13	Sdcard shield	SD SCK	SoftSPI
SDA/SCL	RTCDS1307	SDA/SCL	I2C
SDA/SCL	LCD 20x4	SDA/SCL	I2C
39	Keypad	Row 0	Keymap
37	Keypad	Row 1	Keymap
35	Keypad	Row 2	Keymap
33	Keypad	Row 3	Keymap
31	Keypad	Column 0	Keymap
29	Keypad	Column 1	Keymap
27	Keypad	Column 2	Keymap
2	Indicator Write	LED	out high
3	Indicator Error	LED	out high

performed using four temperature sensors calibrated with the hygrometer's sensors. The relative humidity value was obtained from Equations 1–4 by measuring the dry-bulb and wet-bulb temperatures. The pressure (P) value was determined from Equation 6 by measuring the altitude using an altimeter application. The algorithm for calculating relative humidity (H_r) is as follows:

1. Measure altitude.
2. Calculate pressure (P) using Equation 6.
3. Measure dry and wet temperatures.
4. Calibrate dry and wet temperature values.
5. Calculate delta t (Δt) using Equation 2.
6. Calculate e_w, e_d, and A using Equations 3–5.
7. Calculate H_r using Equation 1.

The flowchart for calculating relative humidity is shown in Figure 2.

RESULTS AND DISCUSSION

The instrument consists of dry bulb and wet bulb temperature sensors. The DS18B20s are applied as the sensors are cheap and reliable. The DS18B20 has a fast response to temperature change, although it is not as sensitive and accurate as type-K thermocouple and PT-100 sensors (Topakham and Koonsrisuk, 2025). The DS18B20s work well as the dry and wet bulb sensors, as seen in Table 2. The sensors have a linear response in the

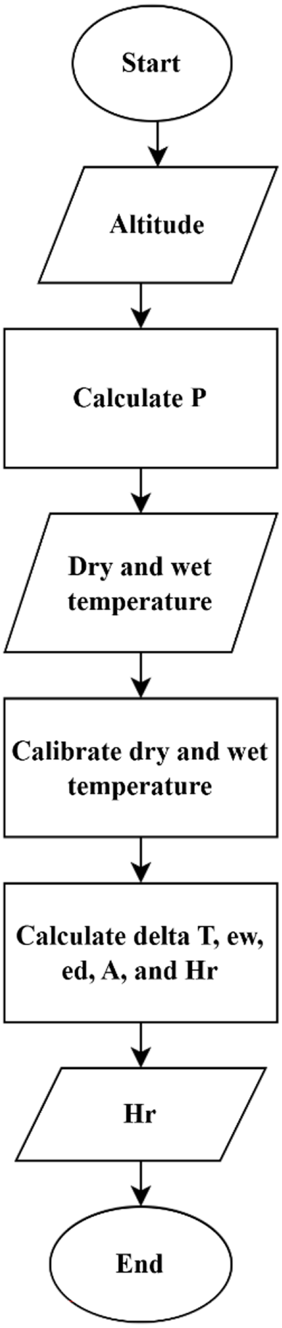


Figure 2. The flowchart of the temperature and relative humidity measurement instrument using the psychrometric hygrometry method

temperature range with high precision and accuracy. These sensors guarantee that the temperature values of the dry bulbs and wet bulbs are reliable. The design results of the temperature and relative humidity measuring instrument based on the psychrometric hygrometry method can be seen in Figure 3. The measuring instrument consists of 4 temperature thermometers (Figure 3b), 4 pairs of dry and wet bulbs, and 4 humidity sensors (Figure 3c). The measuring instrument is provided with a keypad for entering the altitude value. This altitude value is measured using the altimeter application. Figure 4a shows the altitude measurement results, which are 164 m. This value is then entered into the measuring instrument via the keypad and displayed on the LCD (Figure 4b). In this initial display, the LCD also displays the pressure value calculated in the program with Equation 6.

$$P = 101.325(1 - 2.25577\times10^{-5164})5.2559\times10 =$$
$$= 993.703 \text{ mbar}$$

The air pressure is adjusted as it was a very important factor in determining the relative humidity calibration, as mentioned in (Milosevic et al., 2012).

Figure 5 shows the measuring instrument tested to measure temperature and relative humidity in the briquette dryer room (Figure 5a). The first measurement was used to calibrate the sensor with a reference to a Herma brand hygrometer (Figure 5b). This measuring instrument shows the humidity value from the measured dry bulb and wet bulb temperatures. The calibration results are shown in Figures 6–8. The calibration equation is shown in Table 2. The table shows that the average R^2 is 0.9978. All temperature measuring instruments have R^2 above 0.99. An R^2 value approaching 1 indicates that the calibration equation is close to the actual value.

After the calibration process, a second measurement was performed. The second measurement was used to test the calibration results of the measuring instrument. The measurement results were compared with the reference Herma brand hygrometer measuring instrument (Figure 9a). This measuring instrument shows the temperature value of the dry-bulb and wet-bulb temperatures and the humidity that is calculated from the measured dry-bulb and wet-bulb temperatures. The results of the measurements and calculations to obtain relative humidity (H_r) are shown in Table 3. From the measurement results using the hygrometer, it was obtained that the dry temperature = 27.1 °C while the wet temperature = 22.9 °C. From the results of the measurements of these two temperatures, the relative humidity (H_r) value was then calculated, so that the relative humidity (H_r) value was obtained at 69.96. Using the hygrometer shown in Figure 9(b), both values only gave H_r = 65%. The hygrometer value is displayed based on sea-level pressure conditions.

Following the work of Huang et al. (2013), the wet and dry bulb temperatures provide a

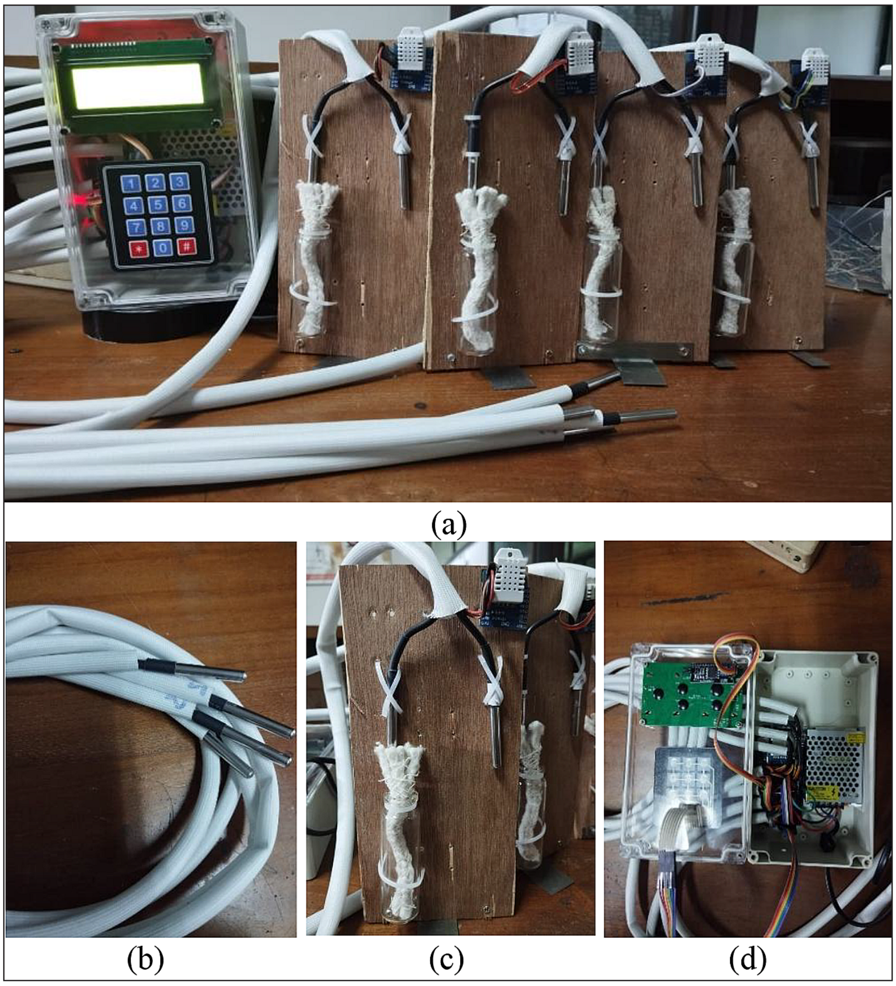


Figure 3. The instrument design: (a) overall instrument, (b) four temperature sensors, (c) dry bulb and wet bulb, (d) humidity sensor electronic circuit

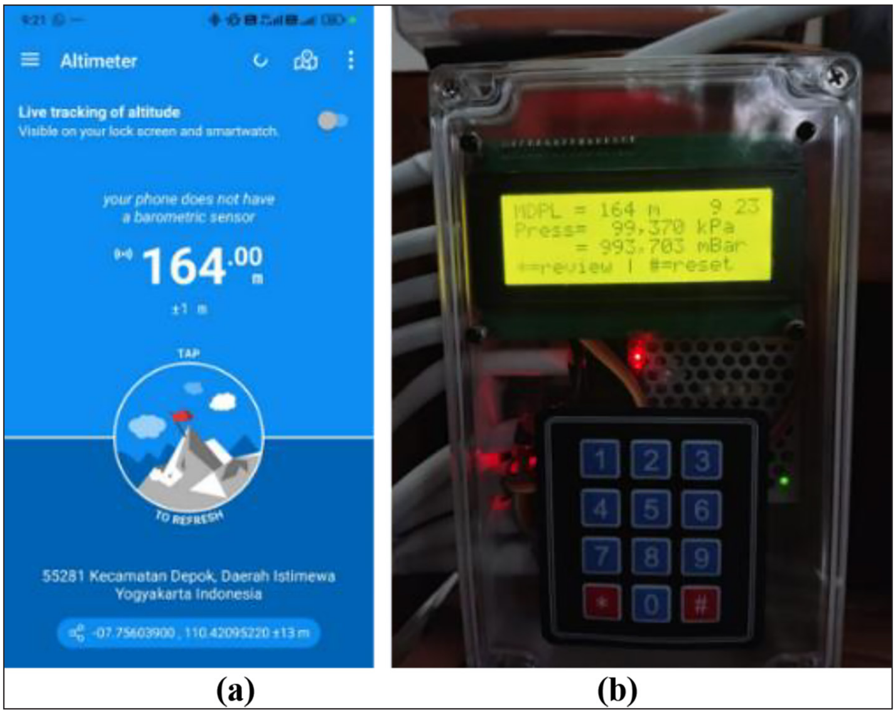


Figure 4. The altitude measurement: (a) measurement result, (b) keypad and LCD display

(a) (b)

Figure 5. The measurement testing: (a) temperature and relative humidity sensors, (b) Herma brand hygrometer

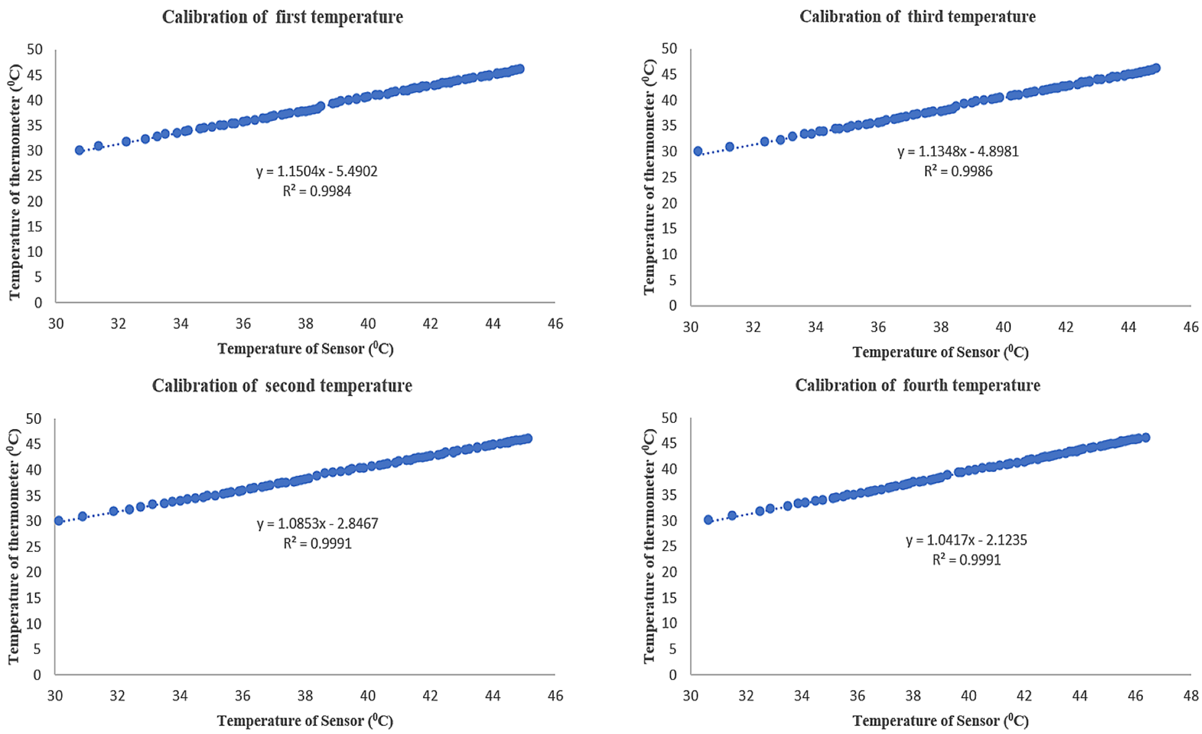


Figure 6. The calibration of a single temperature measurement

relative humidity of 68.74%. The value results in a difference of 1.7% with the designed hygrometer. In addition of 4% maximum difference due to numerical calculation, the current work used 164 m altitude as the reference instead of sea level. The altitude difference between the current work and Huang's work implies a difference in pressure reference. Similarly, the Herma instrument is also designed to apply the 0.101325 MPa. Table 4 shows the error calculations for the measurements and calculations for the designed instrument.

These errors consist of:

1. Error between the dry temperature of the instrument and the dry temperature of the hygrometer Table 4 shows that the average error for dry temperature is 0.93%. The highest error,

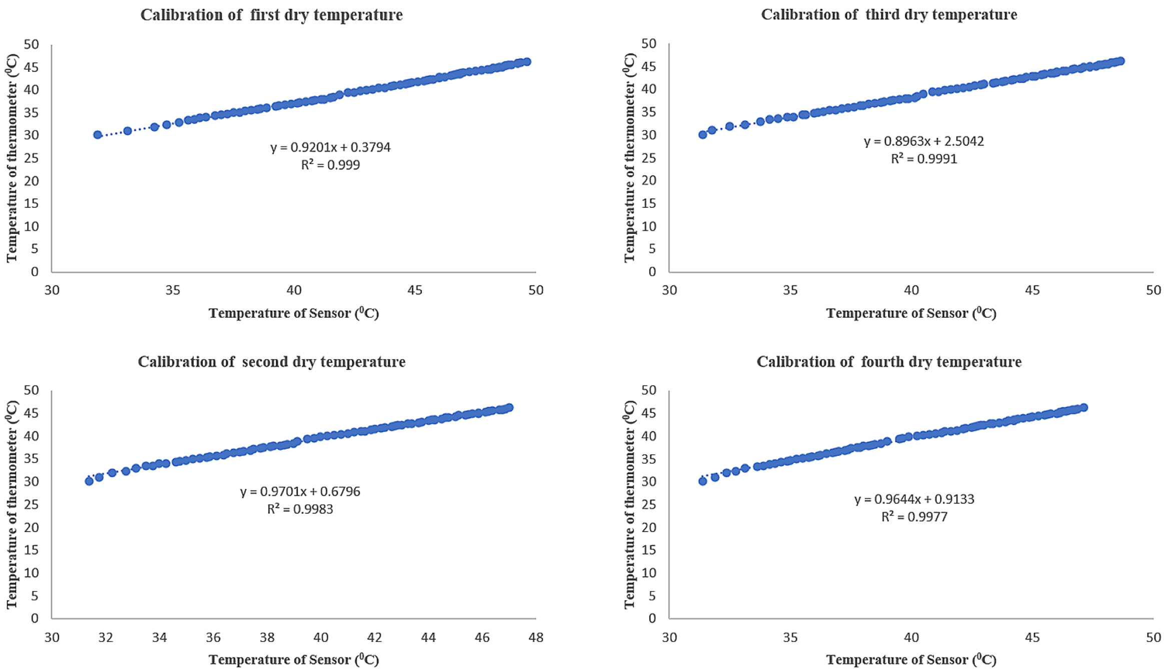


Figure 7. The calibration of dry temperature measurement

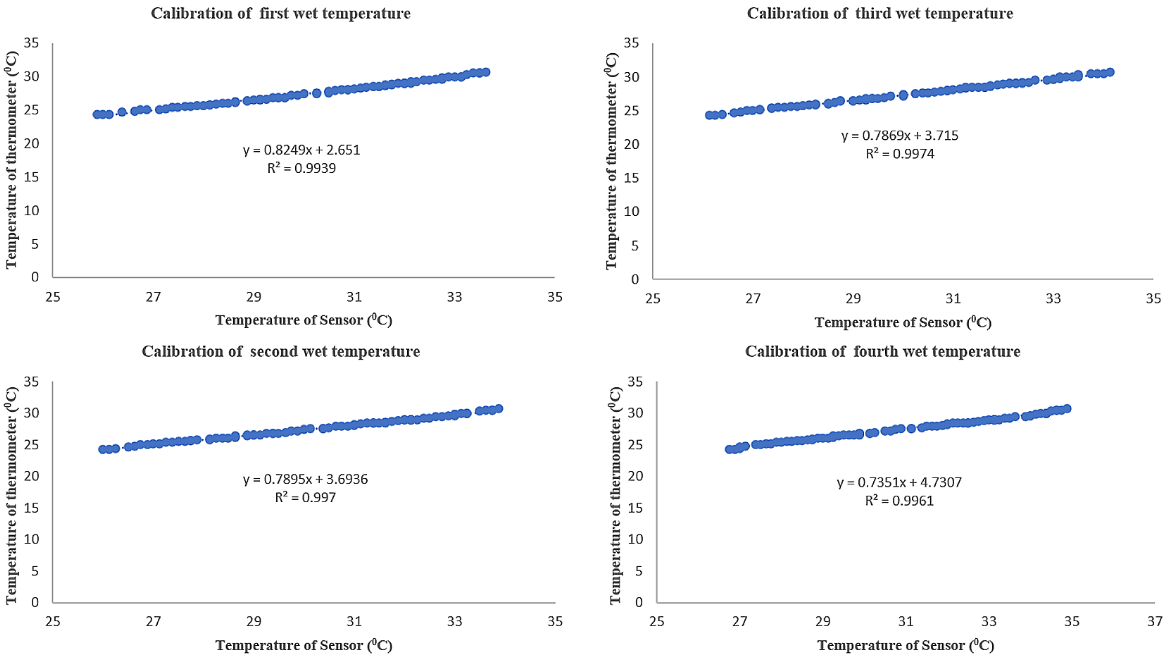


Figure 8. The calibration of wet temperature measurement

1.11%, occurred in the dry temperature measurements on instruments 1 and 2, while the error for instruments 3 and 4 was only 0.74%.

2. Error between the wet temperature of the instrument and the wet temperature of the hygrometer. Table 4 shows that the average error for wet temperature is 1.42%, higher than the error for dry temperature measurements. This error can occur due to the different sizes of the water tubes in the designed instrument and the water container in the hygrometer, as shown in Figure 10. The same applies to the size and material of the wick connecting the sensor and the water. The highest error, 2.62%, occurred in the wet temperature measurements on instrument 3. No error occurred in instrument 2.

Table 2. Calibration equation

Temperature measurement	Calibration Equation	R^2
First temperature	1.1504x - 5.4902	0.9984
Second temperature	1.0853x - 2.8467	0.9991
Third temperature	1.1348x - 4.8981	0.9986
Fourth temperature	1.0417x - 2.1235	0.9991
First dry temperature	0.9201x + 0.3794	0.9990
Second dry temperature	0.9701x + 0.6796	0.9983
Third dry temperature	0.8963x + 2.5042	0.9991
Fourth dry temperature	0.9644x + 0.9133	0.9977
First wet temperature	0.8249x + 2.651	0.9939
Second wet temperature	0.7895x + 3.6936	0.9970
Third wet temperature	0.7869x + 3.715	0.9974
Fourth wet temperature	0.7351x + 4.7307	0.9961
Average		0.9978

Table 3. Results of temperature measurements and humidity calculations

Variable	Instrument				Hygrometer
	1	2	3	4	
Dry temperature, T_d (°C)	27.4	27.4	27.4	27.4	27.1*
Wet temperature, T_w (°C)	22.4	22.9	23.5	22.7	22.9*
Saturation vapor pressure in the dry bulb, e_d)	36.49	36.49	36.28	36.28	35.86**
Saturation vapor pressure in the wet bulb (e_w)	27.08	27.92	28.95	27.58	27.92**
Humidity coefficient (A)	6.77×10^{-4}	6.77×10^{-4}	6.78×10^{-4}	6.77×10^{-4}	6.77×10^{-4}***
Relative humidity (H_r)	64.99	68.19	72.73	67.48	69.96**
Relative humidity sensor DHT22	69.7	70.3	71.7	72.4	-

Note: * The temperature is measured using a hygrometer, ** The value is calculated using the equation with dry and wet temperature measured using a hygrometer.

(a) (b)

Figure 9. The result of the measurement

3. Relative humidity (H_r) calculated using the instrument from the H_r calculation, calculated based on dry and wet temperatures measured using a hygrometer. Table 4 shows that the average error for relative humidity in the designed instrument is 4.29%, with the highest error of 7.11% occurring in the relative humidity calculation using instrument 1, while the lowest error occurred in instrument 2.
4. Relative humidity (H_r) calculated using the instrument from H_r calculation, measured based on dry and wet temperatures measured using

Table 4. Error calculation

Variable	Error of instrument (%)				Average error (%)
	1	2	3	4	
Dry temperature	1.11	1.11	0.74	0.74	0.93
Wet temperature	2.18	0.00	2.62	0.87	1.42
Relative humidity (H_r) from H_r calculation	7.11	2.53	3.95	3.55	4.29
Relative humidity (H_r) from H_r at hygrometer	0.02	4.91	11.89	3.82	5.16
Relative humidity (H_r) from H_r at DHT22	6.76	3.00	1.44	6.80	4.50
Average					3.26

(a) (b)

Figure 10. Water container

a hygrometer, as shown in Figure 9b. Table 4 shows that the average error for relative humidity in the designed instrument is 5.16%. The highest error, 11.89%, occurs in the relative humidity calculation using instrument 3. This could be due to the high wet temperature error in instrument 3.

5. Relative humidity (H_r) calculated on the instrument from H_r measured with the DHT22 sensor. Table 4 shows that the error in the calculated relative humidity of the designed instrument compared to the measurement results from the DHT22 sensor is 4.5%. This result is still relatively small (below 5%), so the designed measuring instrument can be used to measure relative humidity.

Table 4 shows that the average error in the temperature measurements and relative humidity calculations is 3.26%. With an error below 5%, the designed measuring instrument performs well.

CONCLUSIONS

In this research, a temperature and relative humidity (H_r) measuring instrument has been created using DS18B20s humidity sensor and evaluated. Relative humidity is calculated based on the Psychrometric Hygrometry method, where relative humidity calculations are targeted at the temperature in the dry and wet bulbs. In general, the measuring instrument designed is capable of measuring temperature and relative humidity below 5% uncertainty. The tool is capable of measuring temperature with an error below 2%. When compared with the relative humidity calculation with the temperature measured using a hygrometer, the measuring instrument has an error of 4.29%. When compared with the DS22 humidity sensor, the error that occurs is 4.5%.

Acknowledgements

The Authors express gratitude for Direktorat Penelitian dan Pengabdian kepada Masyarakat, which is supporting the research of this work with a grant number of 126/C3/DT.05.00/PL/2025, 0498.1l/LLS-INT/AL.04/2025, and 033 Penel./LPPM-USD/VI/2025,

REFERENCES

1. American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). (2001). Chapter 6. Psychrometrics. In *2001 ASHRAE Fundamentals Handbook (SI)*. ASHRAE.
2. Aosong Electronics Co.,Ltd, *Digital-output relative humidity & temperature sensor/module DHT22 (DHT22 also named as AM2302)*, https://libguides.csudh.edu/ld.php?content_id=52097964
3. Butler, C. J., Garcia-Suarez, A. M. (2012). Relative humidity at Armagh Observatory, 1838–2008.

International Journal of Climatology, 32, 657–668. https://doi.org/10.1002/joc.2302

4. Chen, H. Y.; Chen, C. C. (2022). An empirical equation for wet-bulb temperature using air temperature and relative humidity. *Atmosphere*, 1313, 1765. https://doi.org/10.3390/atmos13111765
5. Harini, B. W., Sambada, R., Muda, V.H.P., Prasetyadi, A. (2025). Dryness level measurement of coconut shell charcoal briquettes using plate-shaped electrodes. *NST Proceeding*, 1–9. https://doi.org/10.11594/nstp.2025.5101
6. Hasan, A. (2010). Indirect evaporative cooling of air to a sub-wet bulb temperature. *Applied Thermal Engineering*, *30*(16), 2460–2468. https://doi.org/10.1016/j.applthermaleng.2010.06.017
7. Hasan, A. (2012). Going below the wet-bulb temperature by indirect evaporative cooling: Analysis using a modified ε-NTU method. *Applied Energy*, *89*(1), 237–245. https://doi.org/10.1016/j.apenergy.2011.07.005
8. Huang, Y., Zhang, K., Yang, S., Jin, Y. (2013). A method to measure humidity based on dry-bulb and wet-bulb temperatures. *Research Journal of Applied Sciences, Engineering and Technology*, *6*(16), 2984–2987. https://doi.org/10.19026/rjaset.6.3682
9. Maxim Integrated Products, I. (2019). *DS18B20 Programmable Resolution 1-Wire Digital Thermometer DS18B20 Programmable Resolution 1-Wire Digital Thermometer Absolute Maximum Ratings*. *92*, 1–20. https://www.analog.com/media/en/technical-documentation/data-sheets/ds18b20.pdf
10. Milosevic, N., Stepanic, N., Babic, M. (2012). A relative humidity calibration from 5 °C to 45 °C in a mixed-flow humidity generator. *Thermal Science, 16*(1), 193–205. https://doi.org/10.2298/tsci1201193m
11. Muda, V.H.P, Harini, B.W., Sambada, R., Prasetyadi, A. (2026). Automation of moisture level measurement in charcoal briquettes. In *E3S Web of Conferences 687*, 01012. EDP Sciences. https://doi.org/10.1051/e3sconf/202668701012
12. Prasetyadi, A., Kusbandono, W. (2023, November). High Performance Oven for Coconut Shell Charcoal Briquetting. In *4th Borobudur International Symposium on Science and Technology 2022 (BIS-STE 2022)* 101–110. Atlantis Press. https://doi.org/10.2991/978-94-6463-284-2
13. Purwadi, P. K., Prasetyadi, A. (2024, July). Air circulation types on Albizia Chinensis refrigerated drying. In *AIP Conference Proceedings 3077*(1), 050011. AIP Publishing LLC. https://doi.org/10.1063/5.0201391
14. Rajkumar, P. (2025). Humidity and temperature monitoring using Raspberry Pi via RS232 networking. *Array*, *27*, 100464. https://doi.org/https://doi.org/10.1016/j.array.2025.100464.
15. Rani, D. (2022). Testing accuracy of dry bulb and wet bulb thermometer in measuring humidity. *Applied Science & Engineering Journal for Advanced Research*, *1*, 14–18. https://doi.org/10.54741/asejar.1.3.2
16. Satra, R., Hadi, M. S., Sujito, S., Febryan, F., Fattah, M. H., Busaeri, S. R. (2024). IoAT: Internet of aquaculture things for monitoring water temperature in tiger shrimp ponds with DS18B20 sensors and WeMos D1 R2. *Journal of Robotics and Control (JRC)*, *5*(1), 62–71. https://doi.org/10.18196/jrc.v5i1.18470
17. Shallcross, D. C. (2005). Preparation of psychrometric charts for water vapour in Martian atmosphere. *International Journal of Heat and Mass Transfer*, *48*(9), 1785–1796. https://doi.org/https://doi.org/10.1016/j.ijheatmasstransfer.2004.11.015
18. Sinaga, D., Sirait, D. B., Pakpahan, K. K., Sihombing, M., Hutauruk, H. (2026). Design and implementation of an ESP32-Based IoT smart room system with automated temperature, ventilation, and lighting control. *Journal of Intelligent Systems, Embedded Systems, and Computer Engineering*, *1*(1), 1–11. https://doi.org/10.65358/rva03t27
19. Suwardono, A., Prahesti, F. E., Indrawati, E. M., Ashofa, M. A. J. (2024). IoT based catfish farm monitoring with ESP32 microcontroller and DS18B20 sensor. *JST (Jurnal Sains dan Teknologi)*, *13*(3), 508–516. https://doi.org/10.23887/jstundiksha.v13i3.85996
20. Topakham, C., Koonsrisuk, A. (2025). Beyond static accuracy: Exploring the ideal temperature sensor for dynamic DCHE environments. *International Journal of Refrigeration, 174*, 86–97. https://doi.org/10.1016/j.ijrefrig.2025.03.006
21. Ustymczuk, A., Giner, S.A. (2011). Relative humidity errors when measuring dry and wet bulb temperatures. *Biosystems Engineering*, *110*(2), 106–111. https://doi.org/10.1016/j.biosystemseng.2011.07.004
22. Wu, M. S., Pu, C., Zhang, Liu, W., Han, S., Fu, J., Duan, S. (2024). Triple-channel optical fiber surface plasmon resonance sensor for simultaneous detection of relative humidity, magnetic field, and temperature. *IEEE Sensors Journal, 24*(14), 22439–22443. https://doi.org/10.1109/JSEN.2024.3407788
23. Yang, L., Pabalan, R. T., Juckett, M. R. (2006). Deliquescence relative humidity measurements using an electrical conductivity method. *Journal of Solution Chemistry, 35*(4), 583–604. https://doi.org/https://doi.org/10.1007/s10953-005-9015-8
24. Zhang, J., Shen, X., Qian, M., Xiang, Z., Hu, X. (2021). An optical fiber sensor based on polyimide coated fiber Bragg grating for measurement of relative humidity. *Optical Fiber Technology*, *61*, 102406. https://doi.org/10.1016/j.yofte.2020.102406