# METHOD OF READING AND CALIBRATION OF THERMAL SENSORS PT100 VIA WEB SERVER WITH ESP32

## PHƯƠNG PHÁP ĐỌC VÀ HIỆU CHUẨN CẢM BIẾN NHIỆT ĐỘ PT100 THÔNG QUA WEB SERVER VỚI ESP32

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**Abstract -** This study proposes a temperature sensor reading and calibration method using the MAX31865 module to process signals from the thermal sensor PT100 via the ratio measurement method. Temperature is determined using both calculation and table lookup methods, then displayed on a web server and calibrated using the two-point method to minimize errors. The device outputs a voltage signal in the range of 0÷5 V, corresponding to a temperature range of 0÷100°C, which is then converted into a current signal of 4÷20 mA for compatibility with programmable logic controllers. Experimental results demonstrate high accuracy, with an acceptable error within the range of 0÷100°C. While this method achieves acceptable precision, further evaluation over a wider temperature range is necessary to ensure suitability for industrial applications.

**Key words -** Thermal sensor; Read and calibrate; Web server

**Tóm tắt -** Nghiên cứu này đề xuất một phương pháp đọc và hiệu chỉnh cảm biến nhiệt độ thông minh, sử dụng mô-đun MAX31865 để xử lý tín hiệu từ cảm biến nhiệt độ PT100 bằng phương pháp đo tỉ lệ. Nhiệt độ được tính toán bằng cả phương pháp tính toán và tra bảng, sau đó hiển thị trên web server và hiệu chuẩn theo phương pháp hai điểm để giảm thiểu sai số. Thiết bị có thể xuất tín hiệu điện áp trong dãy từ 0÷5 V, tương ứng với dải nhiệt độ từ 0÷100°C, và được chuyển đổi thành tín hiệu dòng điện trong dãy tương ứng từ 4÷20mA để có thể kết nối với thiết bị điều khiển lập trình logic. Kết quả thực nghiệm cho thấy thiết bị hoạt động chính xác với sai số cho phép trong dải đo 0÷100°C. Kết quả cho thấy phương pháp đọc và hiệu chỉnh này đạt độ chính xác phù hợp với ứng dụng công nghiệp nhưng cũng cần tiếp tục đánh giá trong dãy nhiệt độ đo rộng hơn để hoàn toàn phù hợp với các ứng dụng thực tiễn.

**Từ khóa -** Cảm biến nhiệt độ; Đọc và hiệu chuẩn; Web server

## 1. Introduction

Smart sensors have become increasingly important across various fields, from industrial automation to consumer electronics. Beyond measurement, they possess data processing and communication capabilities, thereby optimizing system performance [1, 2].

The emergence of low-cost sensors has driven the need to enhance performance, simplify systems, expand functionality, and reduce design costs [3]. Among these, the research and application of temperature sensor technology have attracted significant attention, with various signal processing methods proposed to improve accuracy. Wang and Yin utilized a Wheatstone bridge circuit and piecewise linear estimation to achieve precise and highly stable temperature measurements, with a three-wire connection improving the measurement accuracy of PT100 sensors to 0.1ºC [4]. Additionally, Wheatstone bridges and LM741 were used to process signals from PT100 sensors, while the ADC0808 converter reduced nonlinearity errors, in combination with an STC microcontroller for temperature display and object control via relay [5]. Meanwhile, Li and colleagues applied a BP artificial neural network combined with the LM algorithm for multipoint calibration, enhancing accuracy [6].

Samuk and Çakır combined a Quarter Bridge circuit with an STM32F4 microcontroller to design a high-precision measurement system [7]. Wang et al. proposed the use of an AD7794 24-bit Sigma-Delta converter and dynamic compensation techniques based on IRTD to improve reliability [8]. Furthermore, Czaja integrated a voltage divider and time-domain measurement method to reduce noise when reading data from PT100 sensors [9].

These studies demonstrate that PT100 temperature sensors are an excellent choice for temperature measurement applications due to their durability and high stability. Therefore, this research focuses on improving the method of reading and calibrating sensors, combined with data transmission to a web server to enhance efficiency and applicability. The proposed temperature measurement device includes the following functions: reading and transmitting data to a web server, high-temperature warning, two-point calibration, and outputting a 4–20 mA current signal for connection to programmable logic controllers (PLC), thereby providing a practical solution for temperature measurement and monitoring.

Currently, many temperature measurement systems using PT100 sensors have been deployed; however, remote monitoring capabilities often require specialized equipment and high technical expertise. Available solutions rarely integrate an intuitive web interface that allows for remote calibration and control. This raises the question: how can a PT100 measurement and calibration system be built that is accurate, cost-effective, easy to deploy, and supports web-based monitoring? This paper proposes an integrated model using ESP32 hardware, MAX31865, MQTT protocol, and Node-RED, along with flexible calibration algorithms to address this issue. The study also applies both single-point and two-point calibration, as well as computational algorithms, to optimize device accuracy.

## 2. Methods

### *2.1. Proposed data acquisition system*

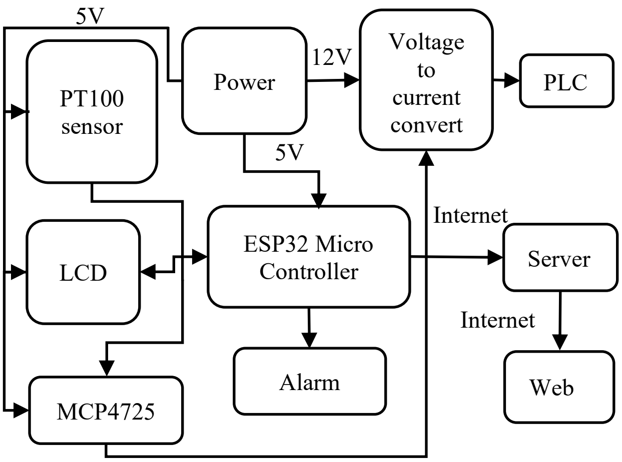



***Figure 1.*** *The diagram of reading and calibrating system for PT100 thermal sensor*

Figure 1 illustrates the general architecture of the PT100 sensor reading system, which uses the ESP32 microcontroller for data processing and communication with the web server. The MAX31865 module processes signals from the PT100 sensor, while the MCP4725 module converts analog signals to digital. Additionally, the HW685 module is used to convert voltage signals to current for connection with a PLC control system, ensuring both flexibility and accuracy. The list of devices and their basic specifications are summarized in Table 1.

***Table 1.*** *List of the equipment used in the system*

| No. | Equipment | Parameters |
|---|---|---|
| 1 | Microcontroller ESP32 | Inclued wifi 2,4 GHz |
| 2 | Thermal sensor Dookwang PT100 | –200 ÷ +650°C |
| 3 | RTD to Digital converter circuit MAX31865 | 3÷5 VDC; SPI |
| 4 | DAC circuit MCP4725 | 2,7÷5,5VDC; 12 Bit; ±0,2 LSB |
| 5 | Voltage to current converter circuit HW685 | 0÷5 V to 4÷20 mA |
| 6 | Power 5V and 12V, resistance, LED, keypad and LCD screen | |

The ESP32 microcontroller receives data from the sensor via SPI and calculates the temperature using either a lookup table method or the Callendar–Van Dusen equation [10, 11]. The calculated temperature is displayed on the LCD and sent to the web server via Node-RED. The website interface displays a chart and supports two-point calibration. In addition, the ESP32 sends data to the PLC via the MCP4725 module, which converts the digital value to a voltage signal, and then to a current signal for PLC connection.

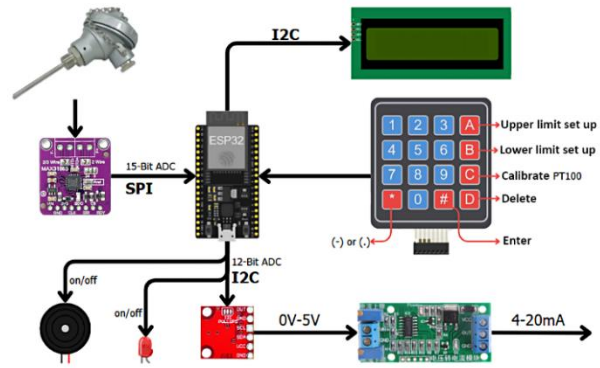



***Figure 2.*** *Equipment connecting diagram*

The connection diagram is shown in Figure 2. The ESP32 microcontroller acts as the central processor, receiving and calibrating data, and connecting to the web server via Wi-Fi for display. The LCD display, keypad, and switches are primarily used for setting alarm limits and calibration parameters for the sensor.

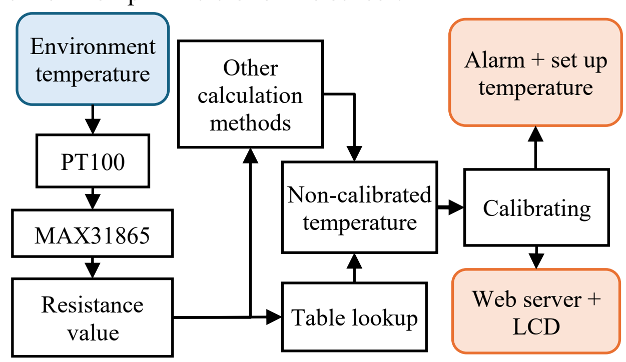



***Figure 3.*** *Block diagram for control*

The block diagram of the control system is presented in Figure 3. The system begins with the PT100 temperature sensor measuring the ambient temperature and converting it into a resistance signal. This signal is fed into the MAX31865 module, which converts it into a digital resistance value. The temperature is then determined by a lookup table to obtain the uncalibrated value. Simultaneously, the system employs other measurement methods to calculate and cross-check the temperature, increasing calibration accuracy. The uncalibrated temperature is processed through a calibration stage, based on the deviation between different measurement methods. After calibration, the accurate temperature value is sent to the web server and displayed on the LCD screen. The system also provides alarm functionality and allows users to set temperature thresholds as required.

### *2.2. Development of the web-based monitoring and control interface using MQTT-Broker, Node-RED, and ESP32*

The temperature data monitoring system utilizes a cloud-based platform with the MQTT protocol, as illustrated in Figure 4 [12]. The PT100 temperature sensor sends data to the ESP32 (client 2), which subsequently publishes the data to the MQTT-Broker. From there, the data is forwarded to the Node-RED application for display and processing. The data flow occurs sequentially as follows:

- The sensor transmits temperature data to the ESP32;
- The ESP32 publishes the data to the MQTT-Broker;
- The computer ("client 1") subscribes to receive the data;
- The computer can also send control commands to the ESP32 via the MQTT-Broker.

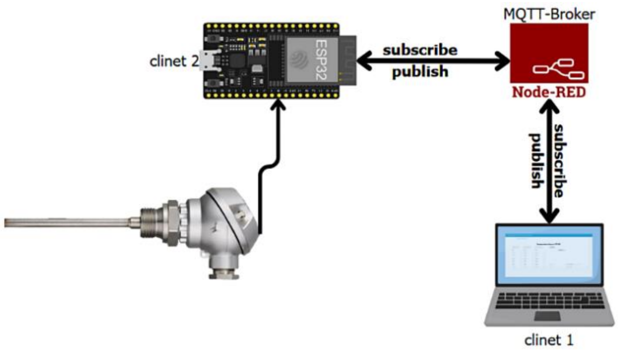



***Figure 1.*** *Web server connecting via MQTT-Broker*

Both the ESP32 and the computer can subscribe to and publish data, enabling real-time system monitoring and control. Meanwhile, Node-RED acts as an intermediary for data management.

### *2.3. Calculation and calibration methods for the sensor*

*2.3.1. Temperature calculation methods*

There are several formulas for calculating the measured temperature value from a temperature sensor operating based on the change in resistance of a conductor with temperature (RTD) [10, 13]. Among these, the Callendar–Van Dusen equation offers the best balance between complexity and accuracy and is presented as follows:

$$t = \frac{-A + \sqrt{A^2 - 4 \times B\left(1 - \frac{R_{RTD}}{R_0}\right)}}{2 \times B} \quad (1)$$

Where:

- $t$ is the measured temperature value (°C);
- $R_{RTD}$ is the resistance of the sensor at temperature t;
- $R_o$ is the resistance of the sensor at 0°C;
- A = 3,9083×10$^{-3}$ and B = –5,775×10$^{-7}$.

Cubic approximation function [10, 13]:

$$t = A + R_{RTD} \times \left(B + R_{RTD} \times \left(C + D \times R_{RTD}\right)\right) \quad (2)$$

Where A = –247.29; B = 2.3992; C = 0.63962×10$^{-3}$ and D = 1.0241×10$^{-6}$.

Polynomial approximation function [10, 13]:

$$t = A + B \times R_{RTD} + C \times R^2_{RTD} - D \times R^3_{RTD} - E \times R^4_{RTD} + F \times R^5_{RTD} \quad (3)$$

Where A = –242.02; B = 2.2228; C = 2.5859×10$^{3}$; D = 4.826×10$^{-6}$; E = 2.8183×10$^{-8}$ và F = 1.5243×10$^{-10}$.

Rational polynomial function [10, 13]:

$$t = A + \frac{R_{RTD}\left(B + R_{RTD}\left(C + R_{RTD}\left(D + E \times R_{RTD}\right)\right)\right)}{1 + R_{RTD}\left(F + R_{RTD}\left(G + H \times R_{RTD}\right)\right)} \quad (4)$$

Where A = –245.19; B = 2.5293; C = –0.066046; D = 4.0422×10$^{-3}$; E = –2.0697×10$^{-6}$; F = –0.025422; G = 1.6883×10$^{-3}$ and H = –1.3601×10$^{-6}$.

*2.3.2. Lookup table method for measured temperature*

The lookup table method is used to determine the temperature from the measured resistance value of the RTD sensor. This method relies on a standard data table, in which each resistance value corresponds to a specific temperature. The lookup table used in this study is based on the BS EN IEC 60751:2022 standard [14].

*2.3.3. Single-point calibration method*

Although the single-point calibration method is relatively simple and easy to use, its calibration results are not as accurate as the two-point method. However, this study utilizes both calibration methods [15].

To perform single-point calibration, the RKC RD900 temperature measuring device and the RKC PT100 probe [16] are first used to read the temperature value of a water sample. The reading provides the actual temperature value for calibration, denoted as $t_{a0}$. Simultaneously, the sensor to be calibrated measures the temperature of the same water sample, yielding the sensor's reading at the calibration temperature, denoted as $t_{m0}$. The actual measured value at any temperature after calibration $t_a$ is calculated as follows:

$$t_a = t_m + \Delta t = t_m + \left(t_{a0} - t_{m0}\right) \quad (5)$$

Where, $t_m$ is the temperature measured by the sensor at any point before calibration (°C).

*2.3.4. Two-point calibration method*

To perform sensor calibration using the two-point method, two measurements are required. One measurement is taken at a low temperature (in the experiment, –5 to 5°C), with the measured value $t_{m1}$ obtained from the developed model and the actual temperature $t_{a1}$ obtained using the RKC RD900 reader and TP100 probe. A second measurement is taken at a higher temperature (in the experiment, 95 to 105°C), with the corresponding measured values $t_{m2}$ and $t_{a2}$.

The correction coefficient $\varepsilon_c$ is calculated as follows:

$$\varepsilon_c = \frac{t_{a2} - t_{a1}}{t_{m2} - t_{m1}} \quad (6)$$

The offset Δ is calculated as:

$$\Delta = t_{a1} - \varepsilon_c \times t_{m1} \quad (7)$$

Each measurement is repeated multiple times, and the average value is used to calculate the coefficients $\varepsilon_c$ and Δ. The actual temperature value after calibration is then estimated as follows:

$$t_a = \varepsilon_c \times t_m + \Delta \quad (8)$$

## 3. Research results and survey

### *3.1. Results of hardware system model construction*

The hardware devices were connected according to the diagram shown in Figure 2, and the results are presented in Figure 5. During the experiment, connectors were soldered to increase the stability of the connections.

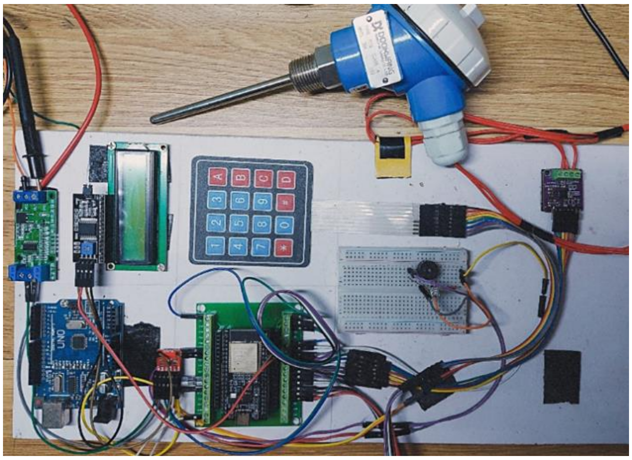


***Figure 5.*** *Hardware connection of the model*

### *3.2. Results of web server interface development*

The web server interface was designed using Node-RED and consists of two pages. The main interface is used to monitor the measured temperature parameters and the sensor status (Figure 6). The calibration interface, shown in Figure 7, is only used when calibration of the PT100 sensor is required.

Users can view temperature, resistance, and DAC signals through charts and status bars, and can also calibrate the device directly via the web interface without editing the source code, saving time and reducing the risk of errors.

### *3.3. Sensor calibration results*

The PT100 sensor calibration interface was run at temperatures of 1.1°C and 96.5°C to obtain calibration parameters (Table 2). These parameters were then entered to perform sensor calibration.

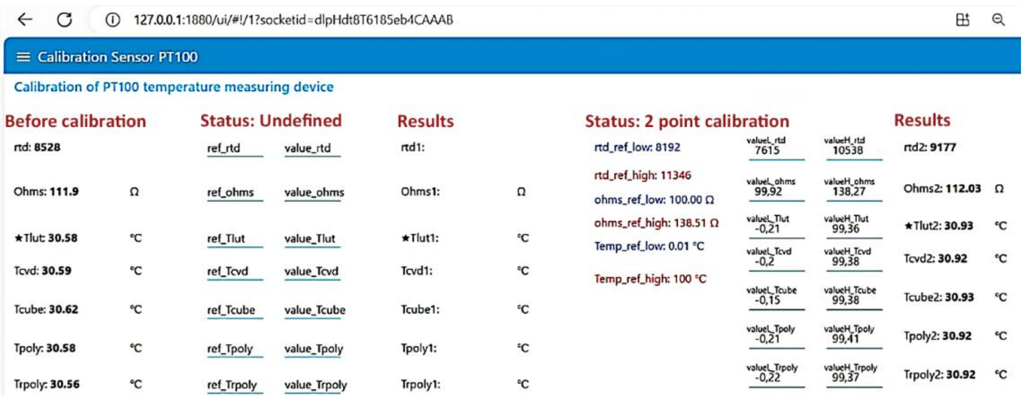



***Figure 6.*** *Main user interface in web server*

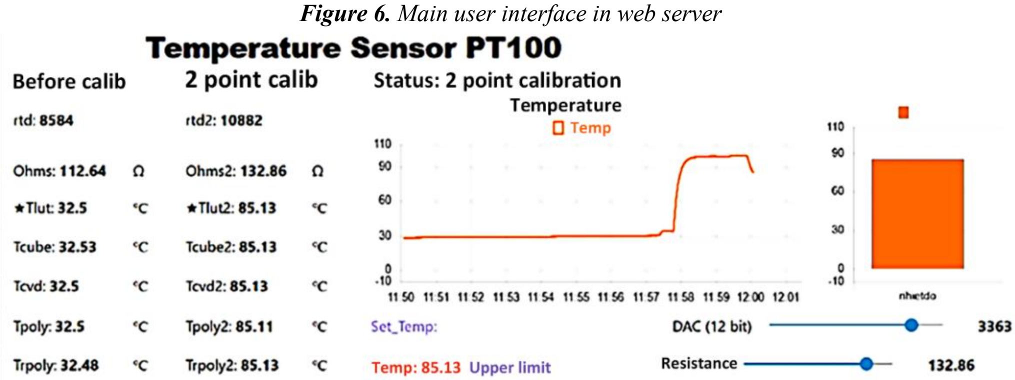



***Figure 7.*** *Calibrating interface*

To evaluate the calibration results from this study, an independent device consisting of an RD900 temperature probe and a PT100 sensor from RKC [16] was used to simultaneously measure the temperature of the water sample as shown in Figure 8b. Table 2 presents the temperature readings from the sensor after calibration with the web server. Among these, the two temperatures 1.1°C and 96.5°C were used for sensor calibration. The other values, 31.5°C, 62.9°C, and 81.4°C, were randomly selected for assessment. Each measurement was performed 20 times to record the average value, as shown in Table 2.

## 4. Discussion

Comparing the results in Table 2, in general, all methods yield relatively small errors, not exceeding 0.24°C. Specifically, the average error in descending order occurs in the lookup table method (0.21°C), cubic function (0.20°C), rational polynomial approximation (0.20°C), polynomial approximation (0.18°C), and the Callendar–Van Dusen function (0.16°C). The calibration values obtained using the Callendar–Van Dusen function have both the lowest maximum error and average error, at 0.16°C and 0.22°C, respectively, and are therefore recommended for use.

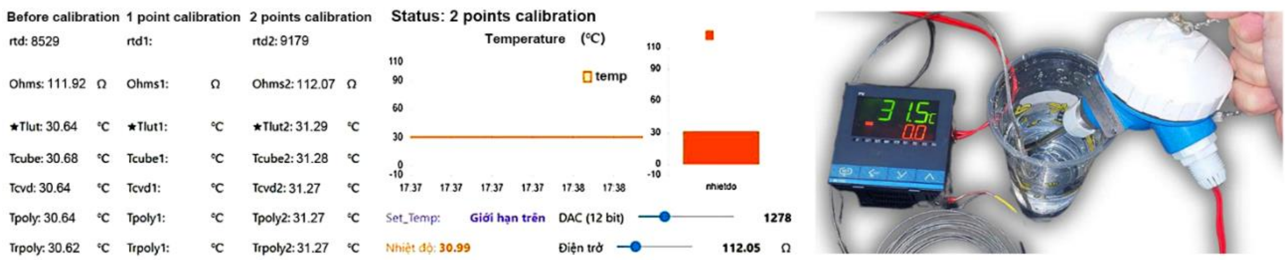
The temperature data measured using this method is stored in the cloud and transmitted to remote control devices via the internet, expanding the range of remote control. However, the system requires additional supporting components, such as protective casings, cooling fans, isolation between power and control circuits, backup batteries, and a 4G mobile network.

***Table 2.*** *Temperature reading results after calibration*

| Testing temperature (°C) | Reading temperature after calibrating (°C) | | | | |
|---|---|---|---|---|---|
| | $T_{lut}$ | $T_{cvd}$ | $T_{cube}$ | $T_{poly}$ | $T_{rpoly}$ |
| 1.1 | 1.31 | 1.26 | 1.32 | 1.30 | 1.33 |
| 31.5 | 31.29 | 31.28 | 31.27 | 31.272 | 31.27 |
| 62.9 | 63.08 | 62.98 | 63.01 | 62.97 | 63.00 |
| 81.4 | 81.62 | 81.59 | 81.63 | 81.64 | 81.64 |
| 96.5 | 96.42 | 96.42 | 96.38 | 96.39 | 96.40 |
| Mean error (°C) | 0.21 | 0.16 | 0.20 | 0.18 | 0.20 |
| Max error (°C) | 0.22 | 0.22 | 0.23 | 0.24 | 0.24 |

The RKC RD900 temperature controller uses a fuzzy control system. When used in the temperature range of 0–99°C, the display has a reading resolution of 0.1°C. The controller is compatible with various types of temperature sensors and can read, display, and control temperatures in the range of –200 to 1,000°C. Resolution is also a factor that affects accuracy and should be added to the calibration error in Table 2. Therefore, the actual average calibration error of the two-point method using the Callendar–Van Dusen function should be (0.16 + 0.1) = 0.26°C.

To interact with control devices such as PLCs, the digital value of the RTD resistance at the 16-bit logic level is converted down to 12 bits to be compatible with the available HW685 conversion circuit. In the current experiment, due to the limitations of the water sample, the test temperature remains within the 0–100°C range. In future studies, when the experimental temperature range is expanded to more broadly evaluate the stability of the measurement method, the conversion value will need to be updated to match the new range.




a) Read out results before and after calibration

b) Comparison with themometer RKC RD900

***Figure 8.*** *Calibration results*

## 5. Conclusion

This study has developed a method for calibrating the PT100 sensor and reading temperature values via a web server with acceptable accuracy within the investigated temperature range. The calculation method based on the Callendar–Van Dusen equation and the two-point calibration approach is recommended. These results provide the capability for remote temperature reading and control at a reasonable cost. However, the temperature range should be further expanded in future studies, and greater attention should be paid to designing for durability and stability of the device.

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