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IoT-Based Monitoring of Evaporator Icing and Electrical Current in Precision Air Conditioning

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ABSTRACT

Precision Air Conditioning (PAC) systems play a critical role in maintaining thermal stability in telecommunication data centers that operate continuously. One common operational issue in PAC systems is evaporator icing, which can degrade heat transfer performance and compromise system reliability, while electrical current instability may indicate abnormal compressor operation. This study proposes an Internet of Things (IoT)-based monitoring system for real-time observation of evaporator temperature and electrical current as an early detection mechanism for potential faults in precision air conditioning systems. The system was developed using an ESP8266 microcontroller, a DS18B20 temperature sensor, and a PZEM-004T current sensor, with Telegram employed as a remote monitoring interface. Experimental testing was conducted on a precision air conditioning unit under normal operating conditions. The results demonstrate that the DS18B20 sensor provides accurate and consistent temperature measurements, with evaporator temperatures recorded within the normal operating range. Electrical current measurements obtained from the PZEM-004T sensor show close agreement with reference multimeter readings, indicating reliable current monitoring performance. The developed system successfully transmits temperature and current data in real time with stable communication performance. By integrating thermal and electrical parameters within a single IoT-based monitoring framework, the proposed system supports early fault detection and preventive maintenance in PAC systems. This approach enhances operational reliability and provides a practical, low-cost monitoring solution for telecommunication data center cooling applications.

Keywords: *internet of things; precision air conditioning; evaporator temperature monitoring; electrical current monitoring; preventive maintenance*

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INTRODUCTION

Precision Air Conditioning (PAC) systems play a critical role in maintaining the thermal stability of telecommunication data centers that operate continuously on a 24-hour basis. Network equipment such as servers, routers, and switches generates substantial heat due to intensive data processing activities, thereby requiring cooling systems with high temperature and humidity stability to ensure reliable operation. Failure of the cooling system may lead to overheating, performance degradation, component damage, and even service downtime, which can significantly affect the continuity of telecommunication services (ASHRAE, 2021; Zhang et al., 2018).

One of the common issues encountered in precision air conditioning systems is the formation of ice on the evaporator surface. This phenomenon is generally caused by disturbances in the refrigeration system, such as improper refrigerant flow, capillary tube blockage, or operation below the recommended temperature range. Evaporator icing inhibits effective heat transfer, resulting in reduced cooling capacity and increased compressor workload, which may accelerate system degradation (Cai et al., 2019; Kim & Braun, 2020). In addition, instability in the electrical current supplying the PAC system directly affects compressor performance and other electrical components, potentially leading to premature system failure over prolonged operation (Saidur et al., 2017).

In practice, monitoring of precision air conditioning systems is still predominantly conducted using conventional approaches, including periodic inspections or built-in system alarms. These methods are limited in their ability to provide real-time information on temperature and electrical current conditions and are generally not accessible remotely. Delayed detection of anomalies may therefore result in more severe system failures before corrective maintenance actions can be implemented (Li et al., 2020).

The advancement of Internet of Things (IoT) technology has enabled the integration of sensors, microcontrollers, and internet connectivity to facilitate real-time and remote monitoring of system conditions. Numerous studies have demonstrated that IoT-based monitoring solutions in electrical and cooling systems can enhance operational efficiency and support data-driven maintenance strategies (Gupta & Johari, 2019; Al Faruque et al., 2016). However, most existing IoT-based air conditioning monitoring studies primarily focus on ambient room temperature measurements, without considering electrical current parameters or evaporator conditions that are directly associated with the risk of icing formation.

Addressing this research gap, this study proposes an IoT-based monitoring system for evaporator temperature and electrical current in precision air conditioning systems as an early detection mechanism for evaporator icing and electrical abnormalities. The proposed system utilizes an ESP8266 microcontroller, a DS18B20 temperature sensor, and a PZEM-004T current sensor, with Telegram employed as the monitoring interface. The developed system is designed to provide real-time, simple, and flexible visualization of temperature

Vol. 1, No. 1, February (2026), pp. 46-54 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
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and current data, thereby supporting preventive maintenance activities and enhancing the reliability of cooling systems in telecommunication data center environments.

RESEARCH METHODS

This study employs an experimental and system design–implementation approach to develop an Internet of Things (IoT)-based monitoring system for evaporator temperature and electrical current in Precision Air Conditioning (PAC) units. This approach was selected to ensure that the proposed system operates under real conditions, produces measurable outputs, and can be replicated in similar operational environments.

The object of the study is a precision air conditioning system used in telecommunication network facilities. The monitored parameters include evaporator temperature, which serves as an indicator of potential icing formation, and electrical current, which reflects the operational condition of the PAC electrical and compressor systems.

Evaporator Temperature Monitoring in Precision Air Conditioning

Temperature monitoring focuses on the evaporator outlet of the PAC unit, as temperature stability is critical for maintaining reliable cooling performance in network equipment operating continuously. A DS18B20 temperature sensor was selected due to its high accuracy, stability, and wide measurement range (−55 °C to +125 °C), making it suitable for cooling system applications (Zhang et al., 2019).

The sensor is positioned between the evaporator and the expansion valve to obtain temperature readings that accurately represent actual refrigeration system conditions. In this study, operational temperature thresholds are defined based on PAC working characteristics: temperatures below 5 °C indicate a potential risk of evaporator icing, while temperatures exceeding 22 °C suggest reduced cooling effectiveness and a potential risk of equipment overheating.

Electrical Current Monitoring in Precision Air Conditioning

Electrical current monitoring is conducted to evaluate power supply stability and compressor operating conditions in the PAC system. A PZEM-004T current sensor is utilized to measure alternating current in real time, with a measurement capacity of up to 100 A. This sensor has been widely applied in IoT-based energy monitoring systems due to its reliability and measurement accuracy (Saidur et al., 2017).

The current sensor is installed in a plug-and-play configuration on the PAC power input line without modifying the internal electrical configuration of the system. The acquired current data are used to identify abnormal operating conditions, where current fluctuations may indicate excessive load, electrical disturbances, or degradation in compressor performance.

System Design and Implementation

The monitoring system is developed using an ESP8266 microcontroller as the central data processing and communication unit. The DS18B20 temperature sensor is connected to the ESP8266 via a one-wire configuration with a 4.7 kΩ pull-up resistor, while the PZEM-

Vol. 1, No. 1, February (2026), pp. 46-54 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
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004T current sensor is interfaced through serial communication. The circuit configurations for the temperature and current sensors are presented in Figure 1 and Figure 2, respectively.

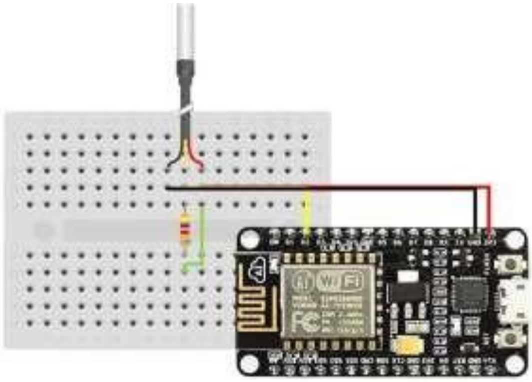

Figure 1. Dallas 18b20 Sensor Circuit

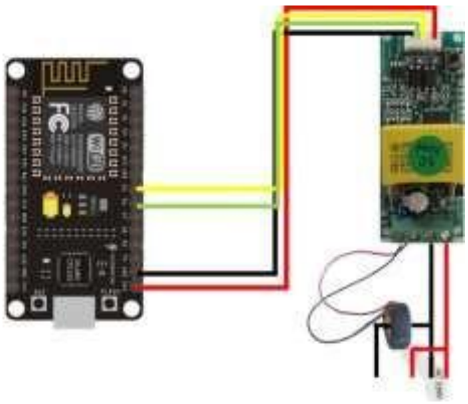

Figure 2. Pzem 004t Sensor Circuit

Measurement data from both sensors are processed by the ESP8266 and transmitted via a WiFi network to the Telegram platform, which serves as the monitoring interface. Telegram is selected due to its ease of access, simple data visualization, and cross-platform compatibility, enabling real-time and remote monitoring without requiring additional dedicated applications.

Sensor Calibration

Calibration of the DS18B20 temperature sensor is performed by comparing sensor readings with a reference thermometer using a water medium at several temperature points. This procedure ensures measurement accuracy and consistency. Temperature values displayed on the Arduino IDE serial monitor are compared with those transmitted to the Telegram interface to verify data integrity during transmission.

Calibration of the PZEM-004T current sensor is carried out by comparing sensor measurements with readings obtained from a digital multimeter under specific electrical load conditions. The measurement deviation is evaluated to ensure that sensor readings remain within acceptable tolerance limits for monitoring applications.

Vol. 1, No. 1, February (2026), pp. 46-54 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
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System Testing and Data Analysis

System testing is conducted directly on the precision air conditioning unit under normal operating conditions. The temperature sensor is placed at the evaporator area, while the current sensor is installed on the PAC power input line. Temperature and current data are collected continuously and displayed in real time via the Telegram interface.

Data analysis is performed using a descriptive–comparative approach, in which sensor measurements are compared with reference instrument readings. System performance evaluation includes sensor accuracy, data transmission stability, and the system's capability to provide real-time monitoring information as a basis for early detection of potential faults in precision air conditioning systems.

RESULTS AND DISCUSSION

Results of the IoT-Based Monitoring System

The experimental results indicate that the developed Internet of Things (IoT)-based monitoring system is capable of performing real-time monitoring of evaporator temperature and electrical current in Precision Air Conditioning (PAC) units via the Telegram application. The tests were conducted to evaluate sensor performance, data transmission reliability, and measurement agreement with reference instruments.

Calibration and Testing Results of the DS18B20 Temperature Sensor

Calibration of the DS18B20 temperature sensor was performed by comparing sensor readings with those obtained from a reference thermometer using a water medium. The calibration results show a high level of agreement between the sensor readings and the reference values, with measurement deviations remaining within acceptable tolerance limits.

Temperature values displayed on the Arduino IDE serial monitor and those transmitted to the Telegram interface were identical, indicating that data transmission from the ESP8266 microcontroller to the monitoring interface occurred without value discrepancies.

During operational testing on the PAC unit, the DS18B20 sensor was positioned at the evaporator area. The measured evaporator temperature was within a range of 12 °C, which falls within the normal operating range of the cooling system. Temperature data were displayed continuously and in real time via the Telegram application, enabling direct observation of evaporator temperature conditions during PAC operation.

Calibration and Testing Results of the PZEM-004T Current Sensor

Calibration of the PZEM-004T current sensor was conducted by comparing sensor measurements with those obtained from a digital multimeter under a specific electrical load. When tested using a laptop charger as the load, the PZEM-004T sensor recorded a current value of approximately 0.3 A, which is consistent with the multimeter readings.

Subsequent testing was performed on the PAC unit under normal operating conditions. The PZEM-004T sensor measured the operating current in the range of 4.1–4.2

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A, while the multimeter indicated a current value of 4.17 A. The observed measurement difference remained within acceptable tolerance limits, demonstrating that the PZEM-004T sensor is capable of accurately measuring the electrical current of the PAC system.

The measured current data were successfully transmitted and displayed in real time through the Telegram interface without noticeable delays, enabling continuous monitoring of the PAC electrical condition.

Monitoring System Performance and Data Presentation

Based on the experimental results, the communication system involving the sensors, ESP8266 microcontroller, WiFi network, and Telegram platform operated in a stable manner. Temperature and electrical current data were received and displayed consistently throughout the testing period.

The integration of evaporator temperature and electrical current monitoring enables simultaneous observation of two critical operational parameters within a single monitoring system. Data presentation through the Telegram interface provides simple and accessible visualization, allowing monitoring results to be observed directly without the need for additional dedicated software.

Discussions

The experimental results demonstrate that the proposed Internet of Things (IoT)-based monitoring system is capable of reliably monitoring evaporator temperature and electrical current in Precision Air Conditioning (PAC) units in real time. The integration of DS18B20 temperature sensors and PZEM-004T current sensors with the ESP8266 microcontroller and the Telegram interface operated stably throughout the testing period, indicating that the system architecture is suitable for practical deployment in cooling applications.

The measured evaporator temperature remained within a range of approximately 12 °C during PAC operation, indicating normal cooling performance and the absence of conditions conducive to icing formation. From a thermodynamic perspective, excessively low evaporator temperatures promote moisture condensation and subsequent freezing on the evaporator surface, which impedes heat transfer and reduces system efficiency (Cai et al., 2019; Kim & Braun, 2020). Therefore, direct monitoring of evaporator temperature provides a critical early indicator for identifying abnormal operating conditions before icing adversely affects the cooling process.

Electrical current measurements showed average values between 4.1 and 4.2 A, which closely correspond to the multimeter reference measurement of 4.17 A. This agreement confirms that the PZEM-004T sensor accurately represents the operating current of the PAC system. From an electrical engineering standpoint, stable current consumption reflects normal compressor operation and healthy electrical conditions, whereas significant current fluctuations may indicate excessive loading, electrical faults, or component degradation (Saidur et al., 2017).

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Compared with previous IoT-based air conditioning monitoring studies, which predominantly focus on ambient room temperature monitoring or general control strategies (Gupta & Johari, 2019; Al Faruque et al., 2016), this study offers an extended contribution by directly monitoring evaporator temperature and incorporating electrical current as an additional diagnostic parameter. This approach aligns with recent research emphasizing the importance of monitoring internal cooling system parameters to enhance system reliability and support preventive maintenance strategies (Li et al., 2020; Zhang et al., 2018).

From a practical perspective, the developed monitoring system can serve as an effective preventive maintenance tool for precision air conditioning systems, particularly in telecommunication data center environments that demand high operational reliability. Real-time visualization of temperature and current data via the Telegram platform enables remote monitoring and facilitates timely maintenance actions when early signs of abnormal operation are detected. From a theoretical standpoint, the findings indicate that integrating thermal and electrical parameters within a unified IoT-based monitoring framework enhances early fault detection capability in precision cooling systems.

Despite these contributions, several limitations should be acknowledged. The proposed system currently monitors only two parameters—evaporator temperature and electrical current—and does not include other potentially influential variables such as refrigerant pressure, humidity, or overall energy consumption. In addition, system testing was conducted on a limited scale and did not encompass long-term performance evaluation under varying operational loads. Future research is therefore recommended to incorporate additional monitoring parameters and to conduct extended testing periods to obtain a more comprehensive assessment of system performance and robustness.

CONCLUSION

Based on the system design, implementation, and experimental evaluation, it can be concluded that the proposed Internet of Things (IoT)-based monitoring system for Precision Air Conditioning (PAC) operates reliably in monitoring evaporator temperature and electrical current in real time. The integration of DS18B20 temperature sensors and PZEM-004T current sensors with the ESP8266 microcontroller and the Telegram interface enables accurate and remotely accessible visualization of PAC operating conditions.

The experimental results indicate that the measured evaporator temperature remains within the normal operating range and that the electrical current measurements are consistent with reference instruments, confirming the reliability of the developed system as a monitoring tool. By integrating thermal and electrical parameters, the proposed system contributes to early detection of potential faults, including evaporator icing and electrical instability, which may adversely affect PAC performance.

From a practical perspective, the developed monitoring system has the potential to support preventive maintenance in telecommunication data center environments that

Vol. 1, No. 1, February (2026), pp. 46-54 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
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require high reliability and continuous operation. The main limitations of this study are the limited number of monitored parameters and the absence of long-term performance evaluation. Future research is therefore recommended to incorporate additional monitoring variables and to conduct extended operational testing to enhance the comprehensiveness and robustness of the system.

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