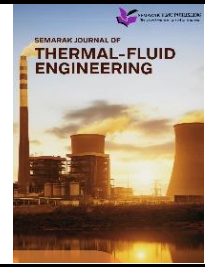




Semarak Journal of Thermal-Fluid Engineering

Journal homepage:
<https://semarakilmu.my/index.php/sjotfe/index>
ISSN: 3030-6639



ThermoGuard IoT: An IoT-Based Extreme Temperature Warning System with Telegram Notification to Support Climate Change Adaptation in Schools

Noormawati Kamaruddin^{1,*}, Shahada Mohd Kassim¹, Faridah Mat Dan¹, Villiah Perdes Nelson¹, Norazian Mohamad¹, Shahada Mohd Kassim¹, Nor Azira Wadiha Azhazid¹, Iman Zara Saiful Bahri¹, Muhammad Avicenna Mohd Zaki¹

¹ Sekolah Kebangsaan Seri Paya, 86400, Parit Raja, Batu Pahat, Johor

ARTICLE INFO

Article history:

Received 3 September 2026

Received in revised form 15 September 2026

Accepted 22 September 2026

Available online 29 September 2026

Keywords:

ThermoGuard; Micro:bit; ESP32;
Telegram; state change detection;
heatwave warning; climate adaptation

ABSTRACT

Heatwave conditions associated with global climate change increase the risk of dehydration and heat stroke among school pupils during outdoor activities. To address the limitations of manual environmental monitoring, this project developed ThermoGuard, a real-time Internet of Things (IoT)-based smart temperature monitoring station. The prototype was developed using the Engineering Design Process (EDP) and integrated a Micro:bit microcontroller, REKA:BIT expansion board, and ESP32 Wi-Fi module within a creatively modified kit-packaging enclosure. The main innovation is the State Change Detection algorithm, which limits notification transmission to a single alert when the thermal status changes and therefore reduces notification flooding. Controlled simulation testing showed that the system successfully activated visual LED indicators and a buzzer and transmitted rapid Telegram notifications when the temperature reached the 38°C danger threshold. Four Telegram transmission tests conducted on 15 June 2026 were successfully received. The findings indicate that ThermoGuard is a practical, low-cost early-warning prototype for improving heat-risk awareness and supporting climate adaptation and STEM education in schools.

1. Introduction

Climate change is one of the major global challenges of the twenty-first century. Excessive human activities that generate greenhouse gases have contributed to increases in the Earth's average temperature and more variable weather patterns [1]. The increasing frequency and intensity of extreme heat events have become an important public-health concern, particularly for populations exposed to high ambient temperatures and prolonged outdoor activities [2]. Malaysia is also directly affected through higher daily temperatures and episodes of extreme heat that can affect public health. School pupils are particularly exposed because they participate in co-curricular activities,

* Corresponding author.

E-mail address: g-80002115@moe-dl.edu.my

<https://doi.org/10.37934/sjotfe.10.1.3947a>

physical education classes, and other outdoor programmes. Prolonged exposure to high temperatures without appropriate control may result in heat exhaustion, dehydration, and heat stroke [3]. Therefore, a smart technology-based intervention is needed as a proactive measure to protect the safety of school communities from environmental thermal risks.

The need for an early-warning system is further highlighted by several incidents reported in Malaysia [4,5]. The source project document refers to a May 2024 case involving an 11-year-old pupil who experienced acute neurological disturbance following heat-stroke exposure [6]. It also refers to an April 2026 report involving three students in Kemaman who were taken to hospital after a cross-country event and were reported by the Terengganu State Education Department as experiencing chronic dehydration and exhaustion [7]. The source further mentions reported child deaths in Kelantan in 2023 suspected to be associated with heat stroke [8]. These events highlight a gap in localised, real-time temperature monitoring. ThermoGuard was therefore developed to monitor micro-level heat changes and distribute rapid digital warnings, supporting community adaptation to climate risks in line with SDG 13 (Climate Action). The development of such a system requires the integration of temperature sensing, embedded processing, wireless communication, and automated warning functions into a single practical monitoring platform [9].

Subsequently, increasing weather anomalies and extreme heatwaves represent a critical physical-safety issue for communities [10]. However, institutions may still rely on manual and subjective observation to determine whether outdoor activities are safe. School administrators and local activity managers face difficulties in detecting increases in ambient temperature in real time because an automated, simple, smart, and cost-effective local monitoring system is not readily available [10]. This creates a surveillance gap in relation to microclimatic changes around the school environment. Addressing this gap requires a system capable of continuously acquiring temperature data, processing the measured values against a predefined safety threshold, and delivering timely warnings to users. The system must also be sufficiently compact, reliable, low-cost, and easy to deploy within a school environment. This concern is particularly important because heat exposure is not necessarily uniform across locations; high-density and location-specific temperature monitoring can provide more detailed information for identifying areas experiencing elevated heat stress [11].

Delays in receiving accurate information and data logs on environmental temperature variation can prevent timely intervention and safety planning. Consequently, delayed response may increase pupils' exposure to acute health risks such as severe dehydration, heat exhaustion, and heat stroke. A smart technological intervention is therefore required to operate as an accurate, low-cost, automated early-warning mechanism capable of distributing rapid notifications to protect the community and support SDG 13 (Climate Action). The Intergovernmental Panel on Climate Change reported that global temperatures are expected to continue increasing as climate change progresses, potentially producing more frequent extreme heat events [1]. The World Meteorological Organization also reported that 2023 was among the warmest years recorded in the history of global climate observation [12]. Extreme temperature anomalies affect not only ecosystems but also human health.

The World Health Organization has reported a direct relationship between high ambient temperatures and increased risks of heat-related illness and premature mortality [3]. In addressing this global climate and health challenge, Internet of Things (IoT) technology provides an important intervention mechanism because it enables smart monitoring systems to collect environmental data in real time and deliver warning information rapidly to users [7]. Based on the references and synthesis presented in the source project, a self-contained, low-cost, easy-to-use temperature warning system adapted to the environment of a school is therefore relevant. Such a system can

reduce the gap in local thermal-risk management and contribute to sustainable community resilience under SDG 13 (Climate Action).

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In addressing this global climate and health challenge, Internet of Things (IoT) technology provides an important intervention mechanism because it enables smart monitoring systems to collect environmental data in real time and deliver warning information rapidly to users [10]. Based on the references and synthesis presented in the source project, a self-contained, low-cost, easy-to-use temperature warning system adapted to the environment of a school is therefore relevant. Such a system can reduce the gap in local thermal-risk management and contribute to sustainable community resilience under SDG 13 (Climate Action). Therefore, a real-time IoT-based temperature warning system with Telegram notifications was developed and evaluated to support climate change adaptation in schools.

2. Methodology

2.1 Research Design and Project Development

ThermoGuard IoT was developed using the Engineering Design Process (EDP), comprising six main phases: problem analysis, system design, hardware development, software development, system testing, and system improvement. This approach was used to ensure that the developed system met the project objectives and could function effectively in a school environment.

2.1.1 Problem analysis

The first phase identified the problem arising from increasing environmental temperatures associated with global climate change. Based on observations and the literature reviewed in the source project, increasingly frequent heatwaves can increase the risk of heat stroke and dehydration among pupils involved in outdoor activities. School administration may also depend on manual weather monitoring, which is less efficient and cannot provide real-time early warnings. Delayed information can prevent immediate safety action. Therefore, a smart temperature monitoring system capable of providing automated real-time warnings was identified as necessary to support faster and more accurate school decision-making.

2.1.2 System design

ThermoGuard was designed as a smart temperature monitoring station integrating IoT technology. Micro:bit functions as the main processing unit and uses its built-in temperature sensor. The REKA:BIT expansion board facilitates electronic connections, while the ESP32 Wi-Fi module acts as the communication medium for sending notifications to Telegram. The integration of environmental sensors with microcontrollers and wireless communication provides a practical approach for real-time environmental monitoring [13]. When the temperature reaches the danger threshold of 38°C, the system activates a red LED, an audible buzzer, and a notification message to

the user. When the temperature remains below 38°C, the green LED is activated and the system displays a normal status as shown in Figure 1.

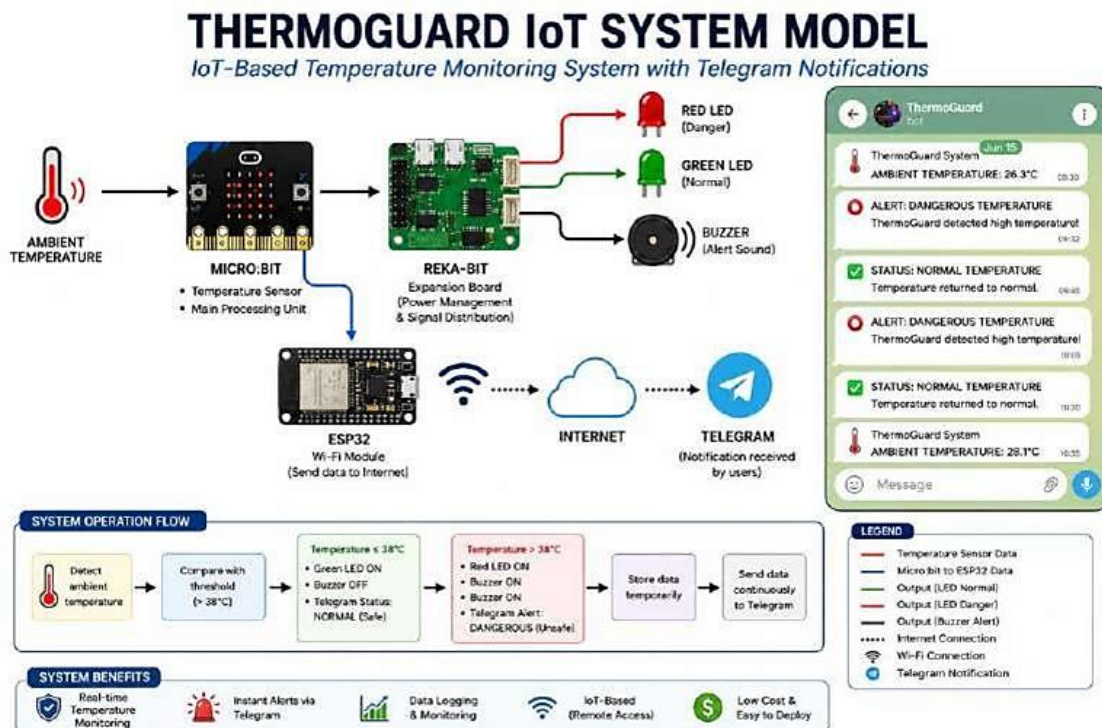


Fig. 1. ThermoGuard IoT system model showing temperature sensing, Micro:bit processing, REKA:BIT integration, ESP32 communication and Telegram notification

2.1.3 Hardware development

Hardware development involved component assembly, pin configuration, and integration of the electronic components to form a stable micro-sensing system. Each selected component supports physical automation and the IoT communication gateway (Table 1). The electronic components were placed inside the original REKA:BIT kit packaging box, which was creatively modified as the system enclosure. This upcycling approach reduced development cost and increased environmental sustainability.

Table 1
Components used in the ThermoGuard model

No.	Component	Function
1	Micro:bit	Main processing unit and temperature sensor
2	REKA:BIT	Expansion board
3	ESP32	Wi-Fi communication module
4	Green LED	Indicates normal status
5	Red LED	Indicates danger status
6	Buzzer	Audible warning
7	Jumper wires	Circuit connections

2.1.4 Software development / control logic

The system software was developed using Microsoft MakeCode. The programme reads temperature data from the Micro:bit, controls the output components, and transmits information to Telegram through the ESP32 module.

2.1.4.1 Temperature threshold logic

ThermoGuard continuously reads ambient temperature in real time using the built-in temperature sensor on the Micro:bit. Real-time environmental sensing and IoT-based monitoring can support the rapid assessment of localised extreme-heat conditions and facilitate timely warning responses [14]. The system was designed around four functional requirements: real-time temperature acquisition, threshold-based decision making, local warning activation, and wireless notification. These requirements guided the programming of the Micro:bit, the control of the LED and buzzer, and the communication between the Micro:bit, ESP32, and Telegram platform. The project sets 38°C as the heatwave danger threshold. The software description in the source document states the threshold as >38°C, while the operational logic classifies the danger state at 38°C and above as shown in Table 2. The system translates the detected temperature into a dual-state response comprising normal and danger conditions. Through this logic, the system operates not only as a local visual display but also as a responsive digital early-intervention gateway for extreme-weather conditions, consistent with the objectives of SDG 13: Climate Action.

Table 2

Engineering logic and ThermoGuard system response

Thermal condition	Physical component response (hardware)	Digital signal and network output (IoT)
Danger ($\geq 38^{\circ}\text{C}$)	Red LED remains on; buzzer is activated; Micro:bit 5x5 LED matrix displays a SAD icon	The string "DANGEROUS" is sent through serial communication to the ESP32, which distributes one real-time extreme-heat warning notification through Telegram
Normal ($< 38^{\circ}\text{C}$)	Green LED is activated and red LED is switched off; Micro:bit displays a SMILE icon; buzzer is fully muted	The string "NORMAL" is sent through serial communication and the Telegram network records the environment as safe for outdoor activity

2.1.4.2 State change detection algorithm

The key innovation of ThermoGuard IoT is the State Change Detection algorithm. The algorithm compares the current thermal status with the previous thermal status to identify changes in environmental conditions. A Telegram warning is sent only once when the state changes from Normal to Danger or from Danger to Normal. Event-based notification strategies can reduce unnecessary communication and repeated data transmission in IoT systems, thereby improving communication efficiency and reducing network overhead [15]. This approach prevents notification flooding, improves user experience, reduces internet-data consumption, and increases communication efficiency between Micro:bit, ESP32, and Telegram.

2.1.4.3 System sketch

The system model illustrates the complete signal pathway from temperature sensing to local visual and audio indicators and finally to the Telegram notification channel, as shown in Figure 1.

2.1.5 System testing

System testing was conducted to ensure that all components operated according to the project objectives. Testing and validation are essential in IoT-based environmental monitoring systems to verify the reliability of sensor measurements, data acquisition, system response, and real-time communication [16]. A controlled simulation was performed using a hair dryer as an artificial heat source. The generated heat was directed toward the Micro:bit temperature sensor to simulate a heatwave condition. During testing, the following parameters were recorded: detected temperature, green and red LED responses, buzzer activation, serial string output, and Telegram message-reception status.

2.1.6 System improvement

Improvements were made based on the testing results. The main improvement was the use of the State Change Detection algorithm to address repeated notification transmission. Event-based alert handling can help prevent duplicate notifications and improve the efficiency of communication in IoT monitoring systems [17]. This improvement increased system stability and ensured that warning messages were sent only when the temperature status changed. The internal arrangement of components was also updated through more systematic cable management to improve prototype safety and durability.

2.2 Data Collection and Testing Method

Data were collected through direct observation of the system response during the simulation process. Systematic data collection and validation are important in IoT-based environmental monitoring to assess sensor measurements, data acquisition, system response, and communication reliability [16]. The collected data comprised Micro:bit temperature readings, LED and buzzer status, serial string output, Telegram notification status, and the effectiveness of the State Change Detection algorithm. All data were recorded systematically and analysed to determine the effectiveness of the system in detecting extreme temperature and providing early warnings.

2.3 System Operation Flow

The operating flow begins when the system is activated (Figure 2). The Micro:bit reads the ambient temperature in real time and compares the reading with the 38°C safety threshold. Real-time environmental monitoring combined with predefined threshold-based alerts is commonly used in IoT systems to support automated detection and early warning when monitored parameters exceed specified limits [18]. If the temperature is below 38°C, the system enters the normal state, activates the green LED, displays the SMILE icon, and sends the "NORMAL" status once to Telegram. If the temperature reaches or exceeds 38°C, the system enters the danger state, activates the red LED and buzzer, displays the SAD icon, and sends the "DANGEROUS" status once to Telegram. The

current state is then stored before the system returns to the start and repeats the environmental temperature check continuously.

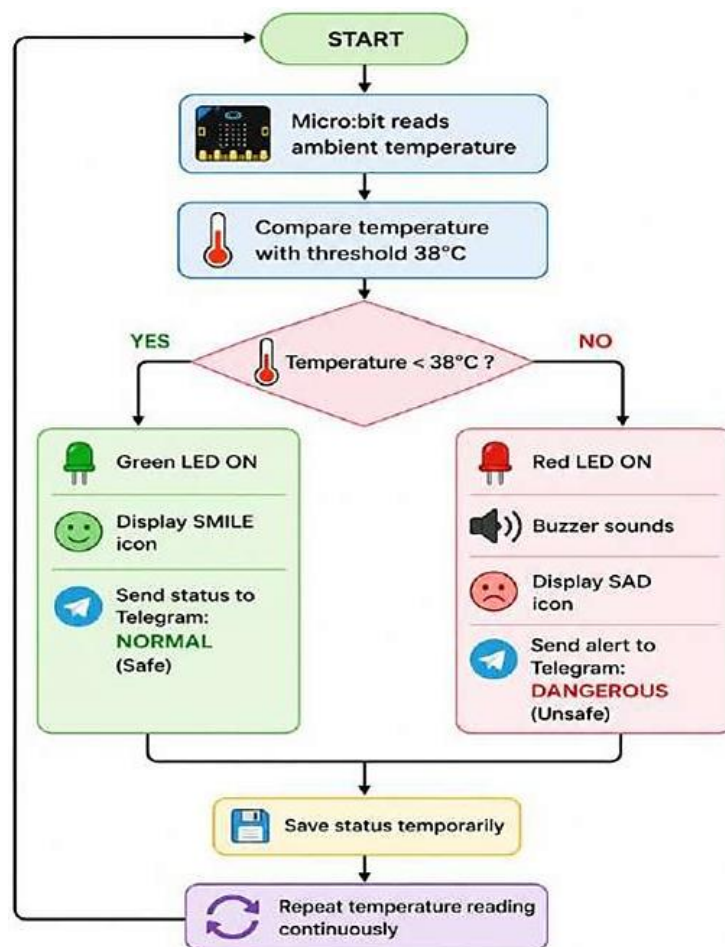


Fig. 2. ThermoGuard IoT operating flow

3. Results

3.1 Test Data

The ThermoGuard IoT test run was conducted on 15 June 2026 on four occasions to evaluate the effectiveness of Telegram notification transmission. Telegram notifications were successfully received in all four tests at 8:45 a.m., 9:08 a.m., 9:23 a.m., and 10:21 a.m as shown in Table 3. The results indicate that the integration of Micro:bit, ESP32 Wi-Fi, and Telegram functioned successfully and was able to deliver notifications in real time. System performance was evaluated based on temperature threshold detection, local warning activation, and Telegram notification transmission. The results were used to assess the responsiveness and reliability of the integrated sensing, processing, and communication functions.

The successful results demonstrate that the communication link between the Micro:bit, ESP32 module, and Telegram platform was operational during the controlled test. The findings support the use of ThermoGuard as an early-warning prototype that can help school personnel respond more rapidly to rising environmental temperatures.

Table 3
ThermoGuard IoT test-run data

Test date	Test	Time	Telegram received?
15 June 2026	1	8:45 a.m.	Yes
15 June 2026	2	9:08 a.m.	Yes
15 June 2026	3	9:23 a.m.	Yes
15 June 2026	4	10:21 a.m.	Yes

3.2 Creativity and Physical Design

The ThermoGuard prototype prioritises practicality, cost saving, and green innovation through reuse of existing materials. The reuse and upcycling of available materials can support circular design approaches by extending material use and reducing the need for new resources in prototype development [19]. The main components are housed in a modified thick cardboard box originally supplied with the REKA:BIT hardware kit. The design provides several distinctive features.

First, the enclosure provides a central display interface. The top surface of the box was neatly cut to create a dedicated display window, allowing the Micro:bit 5 × 5 LED matrix and physical buttons to remain visible from outside. This enables users to read the system's visual status and access the controls without opening the enclosure. Second, external LED indicators are positioned on the left and right sides of the box so that visual warnings can be seen clearly from different angles. Third, reuse of the original packaging supports upcycling and sustainable prototype development, while reducing the need for additional enclosure materials [19].

3.3 Impact on the School Community

The innovation is intended to strengthen the resilience of the school community to climate-change risks. The station supports a climate-aware school environment by making local temperature conditions more visible and actionable [14]. From a safety perspective, the project is designed as an early preventive instrument to reduce the risk of heat-related injury or heat stroke among pupils during co-curricular and other outdoor activities [20]. The project also contributes to STEM education by demonstrating how sensors, microcontrollers, programming, IoT communication, and environmental monitoring can be integrated into a practical school-based application [21].

4. Conclusions

ThermoGuard IoT was successfully developed as a smart temperature monitoring system capable of detecting environmental temperature changes and providing automated early warnings to users. The prototype integrates Micro:bit, REKA:BIT, ESP32, local LED and buzzer indicators, and Telegram communication. Its State Change Detection algorithm limits repeated notifications and improves communication efficiency. Controlled testing on 15 June 2026 produced successful Telegram reception in all four test runs, corresponding to a 100% successful notification rate within the reported test set. With the functional integration, upcycling-based enclosure, and potential for cloud logging and active adaptation, ThermoGuard has potential as a school-based innovation for climate-risk awareness, STEM education, and climate adaptation. The project therefore supports the broader objective of SDG 13: Climate Action.

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