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A Dual-Stage Thermal Alert System for Hypothermia Detection and Emergency Response in Homeless Populations

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***Abstract*—Whilst urban environments are becoming increasingly interconnected through smart city developments, the most vulnerable, particularly those sleeping rough, remain systematically invisible to these advancements. As extreme weather events intensify and homelessness approaches historic peaks, people concealed in parks or abandoned structures face a combination of cold exposures during the sleep process, with no reliable means of detection by outreach teams. This paper presents the Temperature Monitoring Emergency Device (TMED), a low cost IoT prototype that monitors ambient temperature and provides a two stage safety response. First, it activates a local sound and light alarm to wake the user and encourage self rescue. If there is no response, it sends an SMS with GPS location to a predefined contact. The system uses an ESP32 WROOM 32 microcontroller and a SIM808 GSM and GPS module in an IP67 rated enclosure. The results show that the system is technically and economically feasible and highlight the main engineering steps needed to achieve a fully autonomous remote emergency system.**

Index Terms*—*temperature, monitoring, emergency, hypothermia, homelessness, rescue, IoT

I. Introduction

Extreme weather events disproportionately affect the most vulnerable, worsening existing health risks. This directly elevates mortality rates among the homeless population, driven by chronic exposure to harsh conditions and a limited capacity to recover from environmental stresses [1]. In England and Wales alone, approximately 3,000 people died while homeless between 2013 and 2019, with 778 deaths recorded in 2019 [2]. This physical vulnerability is further amplified by a support system that is rapidly reaching its breaking point. Homelessness services are currently facing a "funding cliff-edge" amid unprecedented demand, leaving aid workers increasingly overwhelmed by the complexity of needs presented.

In nations such as the UK, severe economic pressures are forcing nearly half of accommodation providers and shelters to consider closing, precisely at a time when rough sleeping figures are approaching historic peaks [3]. Furthermore, a technological paradox exists within the modern city. Whilst urban environments are becoming increasingly interconnected through digital advancements, the homeless population remains largely invisible within these developments. As "digital transformation" reshapes urban infrastructure, those without access to essential digital resources are being left further behind, deepening their exclusion from the very support systems designed to assist them [4].

As this trend continues, engineering-based solutions must be developed to support the system and advocate for People Experiencing Homelessness (PEH), a group that remains systematically overlooked and underrepresented.

This paper presents the Temperature-Monitoring Emergency Device (TMED): a low-cost, autonomous IoT prototype designed to detect hypothermia risk in rough sleepers and trigger a dual-stage safety response. When the ambient temperature drops to or below 5.0°C, the device activates a local acoustic and visual alarm to wake the user and prompt self-rescue. If the alarm is not acknowledged within a defined grace period, it automatically transmits an emergency SMS containing GPS coordinates to a predefined rescue contact via the cellular network. The system was designed under strict constraints derived from the target deployment context: a total production cost below £83 to enable adoption by charitable organisations, an IP67-rated enclosure for outdoor durability, a 7-day autonomous runtime, and a zero-maintenance user interface operable with gloved hands. A proof-of-concept prototype was developed and evaluated through bench testing, simulated field conditions, and empirical power measurements.

II. Background and Related Work

A. Physiological Basis for Early Intervention

Accidental hypothermia is defined as an unintentional drop in body core temperature (BCT) below 35°C caused by exposure to environmental cold [5]. Sleep significantly increases this risk. Sleep onset is physiologically related to a natural circadian decline in BCT, as peripheral vasodilation in the extremities draws heat away from the body core to support the transition to non-rapid eye movement sleep [4]. For someone sleeping outdoors without adequate insulation, this circadian cooling directly adds to environmental heat loss and accelerates the onset of hypothermia. Fig. 1 illustrates the rate of temperature decline under severe cold exposure.

As BCT drops below 33.5°C, thinking becomes unclear, and alertness decreases [5]. Critically, the body's primary thermal protection (shivering) is suppressed during sleep and completely ceases when BCT drops below 32°C, at which point thermoregulation fails, and the body becomes fully dependent on external heat [6]. This means that a sleeping person can not self-rescue once moderate hypothermia sets in. The intervention window is narrow and occurs early in the cooling process, before the individual loses consciousness. This physiological evidence directly motivates the ambient threshold of 5.0°C used in the TMED design: it provides a

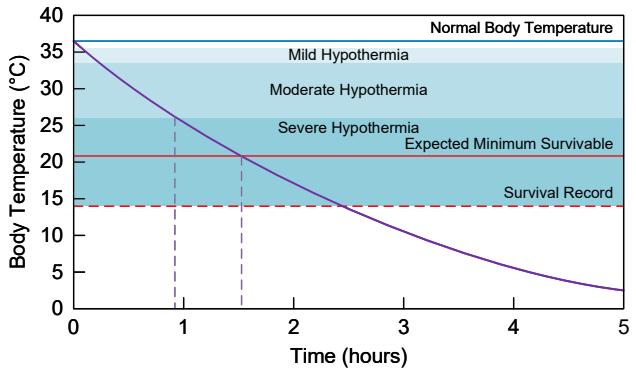


Fig. 1. Body temperature decline vs. time under severe cold exposure (data from [7]).

safety margin that triggers a wake-up alarm before the BCT reaches a dangerous level.

B. Limitations of Existing Solutions

The current cold-weather support infrastructure has two structural gaps. First, stationary solutions such as emergency shelters and modular outdoor sleeping capsules can not locate people who collapse in hidden areas outside of known safe sites [8]. Second, traditional shelters often present entry barriers, such as sobriety requirements, pet restrictions, or a lack of privacy, which lead many rough sleepers to avoid them even in dangerous cold conditions [8]. Outreach teams and cold buses are vital, but they can not provide continuous coverage throughout a city at night [9]. Technology-based approaches have been proposed to fill this gap, but none address the specific constraints of this use case. Wearable sensors based on triboelectric or piezoelectric nanogenerators harvest energy from body motion [10]. This approach is fundamentally unsuitable here because, as hypothermia progresses and the individual becomes still or unconscious, the biomechanical energy drops to near zero precisely when the sensor is needed most [10]. Commercial smartwatches and fitness trackers require regular charging and pairing with smartphones, which are unrealistic requirements for people without stable access to electricity or digital infrastructure [11]. A passive, autonomous system that requires no user charging, no smartphone, and no conscious activation is therefore necessary, yet such a solution does not currently exist on the market.

TABLE I
SYSTEM REQUIREMENTS WITH VALIDATION METRICS

Category	Design Goal (Target Requirement)	Rationale (Validation Metric)
Environmental (G1)	Sub-zero operability: Reliable operation at -10°C	Sensor accuracy and overall operation in cold conditions (7-day runtime)
Environmental (G2)	Ingress Protection: Prevent failure from moisture and pressure differentials	Select components with a certified IP67 rating for moisture and dust resistance
User (G3)	Cost Efficiency: Achieve a scalable, low-cost architecture	Minimise financial risk for charitable organisations to enable mass deployment
User (G4)	Cognitive accessibility: Zero-maintenance, intuitive interface	Operable with gloved hands under physical stress
Security (G5)	Stealth design: Inconspicuous and rugged appearance	Low perceived value reduces theft and assault risk
Connectivity (G6)	Emergency alerting: Transmit an SMS with the location when the alarm is unacknowledged.	Successful SMS delivery to a predefined contact number

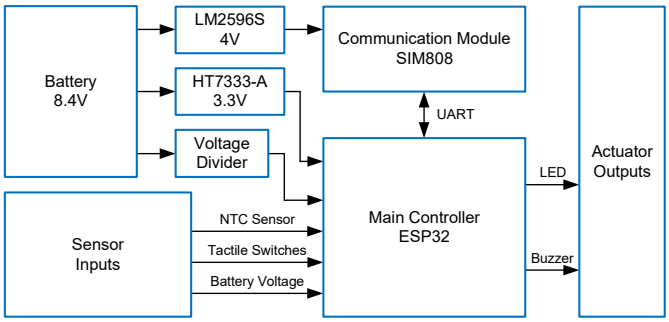


Fig. 2. TMED system architecture and circuit overview

III. SYSTEM DESIGN

A. Requirements

Six design requirements, labelled G1 to G6 (Table I), were derived from three sources: the outdoor operating environment, the constraints of the target user group, and expert insights from a qualitative interview with the DRK Kaltebus Team, a German Red Cross cold weather outreach unit in Ulm, Germany. These requirements served as the evaluation criteria for all component and architectural decisions throughout the project, as well as the validation framework for the test results presented in Section IV. Table I summarises these requirements.

B. Hardware Architecture

The TMED integrates the selected components across two voltage rails within an IP67-rated ABS enclosure. Fig. 2 shows the complete architecture of the system. An LM2596S step-down converter regulates the 8.4 V battery input to a stable 4.0 V rail, which supplies the SIM808 GSM/GPS module. A secondary HT7333-A Low Dropout (LDO) regulator, selected for its ultra-low quiescent current of 4 µA, produces the 3.3 V supply for the ESP32 microcontroller. This dual-rail architecture isolates the sensitive MCU from the high transient loads generated by the GSM module, which can demand up to 2 A in short bursts during network transmission [12]. Temperature sensing uses a 10 kΩ Negative Temperature Coefficient (NTC) thermistor. The thermistor is mounted externally through a waterproof cable gland to decouple the sensor from internal heat dissipation and ensure accurate ambient readings. The user output is provided by an active piezoelectric buzzer and a red LED. An active buzzer was chosen over a passive model because it contains an internal oscillator, producing a consistent 2.3 kHz tone when driven by a HIGH signal, which simplifies control logic and reduces firmware failure points. User input is provided through two stainless steel tactile switches: a latching switch that serves as the main power kill switch, and a momentary switch used to

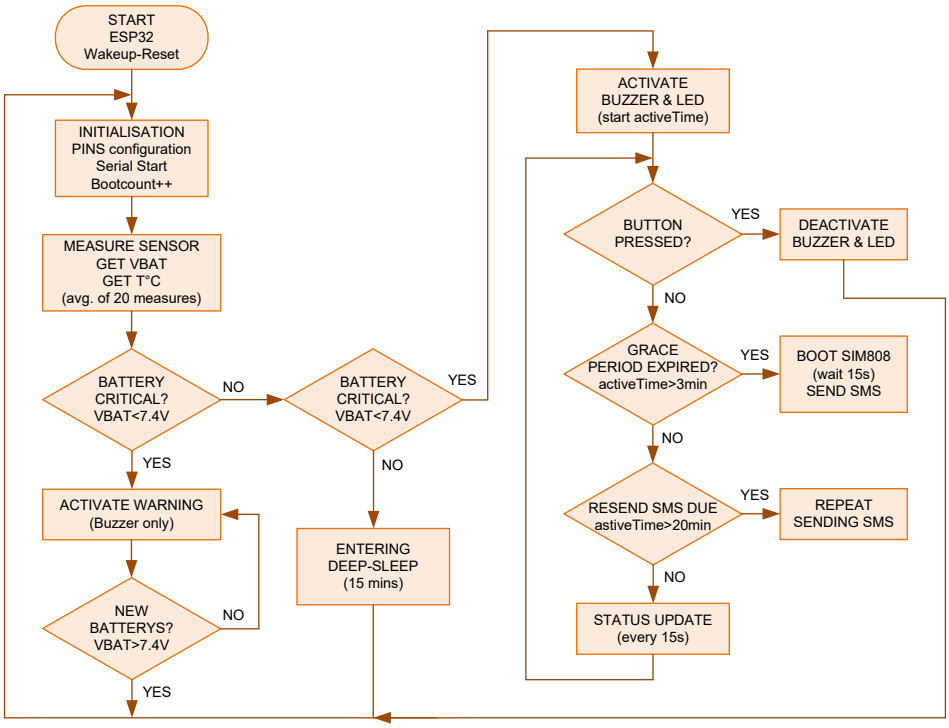


Fig. 3. Flowchart of the TMED's firmware logic.

acknowledge and silence the alarm. Large diameter actuators ensure operability with gloved hands, satisfying G4.

C. Component Selection

The ESP32-WROOM-32 was selected as the central processing unit for its dual-core architecture and deep sleep mode, which reduces the current draw to approximately 10 µA [13]. This is critical to achieving the 7-day runtime target (G1). An initial trial with the single core ESP32-SuperMini-C3 demonstrated insufficient performance when the blocking GSM communication stack was added: the single core caused timing violations in the sensor polling loop. The dual-core ESP32-WROOM-32, using FreeRTOS task scheduling, resolves this by running UART communication and temperature polling on separate cores.

The 10 kΩ NTC thermistor was preferred over a digital alternative (e.g. DS18B20) because it is a passive analogue component with no internal circuitry to fail under freezing or wet conditions and supports interrupt-driven wake patterns that preserve battery life [14], [15].

The SIM808 module was selected for its integrated GSM modem and GNSS receiver in a single package, reducing circuit complexity and component cost compared to using discrete modules. GSM was chosen over LoRaWAN because cellular networks operate on licenced spectrum, ensuring reliable message delivery without duty cycle restrictions, which is a critical requirement for an emergency device [16].

The power supply initially used a single LiFePO4 cell with a nominal voltage of 3.6 V, chosen for its thermal stability. However, testing showed that SIM808's 2 A peak current demand caused the supply voltage to drop below the module's 3.4 V operating threshold, preventing network registration. The design was therefore revised to use two 18650 Li-Ion cells in series, providing a nominal voltage of 8.4 V. This higher voltage offers sufficient headroom to sustain the required current pulses through the LM2596S regulator. The pack has a nominal energy of 25.2 Wh, which is reduced by 20% for the loss of cold-temperature capacity, giving an effective energy of 20.1 Wh. The battery pack was oversized to ensure that the 7-day runtime target is met even at −10°C (G1, G3).

D. Firmware Logic

The firmware is written in C++ using the Arduino IDE framework and implements a state machine with three operational states: deep sleep, local alarm, and remote emergency. Fig. 3 shows the complete control flow.

In a deep sleep state, the ESP32 wakes up every 15 minutes to sample the temperature. The `getTemperature()` function applies 20-sample oversampling to filter ADC noise, then converts the stabilised reading to degrees Celsius using the Steinhart-Hart equation (1), which models the non-linear resistance-temperature relationship of the NTC:

$$T = \frac{1}{A + B\ln(R) + C[\ln(R)]^3} \tag{1}$$

where T is temperature [°C], R is the measured thermistor resistance [Ω], and A, B, C are the Steinhart-Hart coefficients derived from the sensor's nominal resistance (10 kΩ at 25°C) and Beta constant.

When the temperature falls below or below the 5.0°C threshold, the system enters the local alarm state. The threshold was set based on the physiological evidence reviewed in Section II: at ambient temperatures approaching 5°C, the risk of life-threatening hypothermia in an uninsulated sleeping person becomes critical. The alarm drives the buzzer and LED in a non-blocking pattern using `millis()`-based timing, pulsing both actuators on a 50% duty cycle without halting

the CPU. This keeps the button-polling loop active, so that the user can acknowledge the alarm at any time.

If the alarm remains unrecognised after a defined grace period (`GRACE_PERIOD_MS`), the firmware activates the SIM808 module and initiates the remote emergency state. The module registers with the GSM network using AT commands and transmits the GPS coordinates embedded in an SMS to a predefined emergency contact number. The ESP32's FreeRTOS Watchdog Timer is serviced during this blocking loop to prevent an unintended system reset during the multi-second GSM registration process.

Battery protection is implemented in the `setup()` function before any other operation. A voltage divider scales the 8.4 V pack voltage in the ESP32's ADC range. If the reconstructed voltage falls below 7.4 V (approximately 15% remaining capacity), the buzzer activates as a low-battery warning and the system halts before performing any power-intensive tasks.

E. Power Budget

Three operational scenarios were analysed to validate the 7-day runtime requirement (G1).

- Scenario 1: Monitoring. In this case, the only components needing current are the ESP32 and the Negative Temperature Coefficient (NTC) thermistor. To maximise energy efficiency, the ESP32 remains in deep sleep mode and only wakes up every fifteen minutes to perform a temperature measurement.
- Scenario 2: Monitoring with a visual and acoustic alarm. In this scenario, the system activates the visual warning Light Emitting Diode (LED) and the acoustic piezo buzzer for a continuous duration of three minutes before the user acknowledges the alert. The energy intensive SIM808 module remains deactivated during this phase.
- Scenario 3: Monitoring with full alarm cycle. In this scenario, the user shows no reaction, and the SIM808 module is activated to dispatch an emergency Short Message Service (SMS) notification. During this worst-case scenario, the system's power supply is put under heavy stress, as the Global System for Mobile Communications (GSM) communication requires peak currents up to 2 A.

Table II summarises runtimes for all alarm scenarios.

For Scenario 1, daily energy consumption during the assumed 11-hour active night period was calculated as follows. The battery power draw is:

$$P_{Battery} = \frac{P_{Combined}}{\eta_{LM}} + P_{LED} \tag{2}$$

where $P_{Combined}$ = 0.2 W is the sum of ESP32 and LDO power consumption, η_{LM} = 0.8 is the LM2596S efficiency factor, and P_{LED} = 0.168 W is the power drawn by the indicator LED directly from the battery rail. This gives $P_{Battery}$ = 0.418 W during active phases.

Over an 11-hour active night period, the system performs 44 measurements of 2 seconds each (total active time: 0.0244 h), consuming 0.0102 Wh during active phases.

The standby time constitutes 10.9756 hours of the 11-hour nightly period, which consumes 2.4 Wh. The runtime is calculated as follows:

$$t = \frac{E_{Battery}}{E_{Combined}} \tag{3}$$



Fig. 4. Simulated field testing using a refrigerator.

where t is the runtime [days], $E_{Battery}$ is the battery energy [Wh], $E_{Combined}$ is the energy consumed during active and standby periods per day [Wh]. Substituting the above figures into (3) gives a run time for Scenario 1 of 8.39 days. The worst-case full-alarm runtime (Scenario 3, including SIM808) was calculated as 7.86 days from the datasheet figures, confirming that all scenarios meet the 7-day requirement (G1) with margin.

F. Prototype Construction

The prototype progressed from a solderless breadboard to a custom-cut stripboard, then to final integration inside the IP67 ABS enclosure. An ePTFE pressure-equalisation membrane was installed across five enclosure wall apertures to prevent internal vacuum effects during rapid ambient temperature changes and to maximise acoustic output from the buzzer. The NTC thermistor was externally wired through a waterproof cable gland. The completed device is presented in Fig. 4.

IV. Results and Evaluation

Testing proceeded in two phases. At the first stage, the thermal sensing and local alerting core were validated. At the second stage, the full emergency communication path was tested. Results are evaluated against the six design requirements (G1–G6) defined in Table I.

A. Local Alerting Validation

To replicate real-world cold conditions, the device was placed inside a refrigerator set to 3°C and operated continuously, as shown in Fig. 4.

The NTC thermistor accurately detected the temperature drop and activated the local alarm sequence at the 5.0°C threshold (G1). Both the red LED and the piezoelectric buzzer were activated correctly. The user interface responded without

TABLE II
Runtime for Each Scenario

Situation	Current Draining Components	Runtime (days)
Scenario 1: Monitoring	ESP32-WROOM-32D, LM2596S, ON/OFF-Switch Button, NTC Thermistor	8.39
Scenario 2: Alarm	ESP32-WROOM-32D, LM2596S, ON/OFF-Switch Button, NTC Thermistor, LED, Buzzer	8.34
Scenario 3: Full-Alarm	ESP32-WROOM-32D, LM2596S, ON/OFF-Switch Button, NTC Thermistor, LED, Buzzer, SIM808	7.86

errors: the momentary button successfully acknowledged and silenced the alarm, and the latching power switch cleanly deactivated the system (G4). The battery depletion warning also ran correctly; to accelerate this test, the low-voltage threshold was temporarily raised from 7.4 V to 8.0 V against the fully charged 8.4 V pack.

One physical finding from this test was that the acoustic output of the piezoelectric buzzer was quieter than expected when the device was fully enclosed. The ePTFE membrane vents significantly reduced attenuation compared to a sealed enclosure, but the selected buzzer model may need to be upgraded in future iterations to ensure that the alarm is loud enough to wake a sleeping person through heavy winter clothing.

B. Runtime Validation

The current measurements were taken with a digital multimeter in all three operational scenarios. The measured values were then used to recalculate the runtime for each scenario. The measurements consistently produced runtimes longer than the datasheet-based calculations, because the actual operating currents of the ESP32 and the switch LED were lower than the datasheet specifications. The worst-case full-alarm runtime (Scenario 3) improved from 7.86 days to 8.49 days, confirming the operational target of 7-days (G1) with a margin of 21%. The 2 A transient GSM peak current could not be captured with the available multimeter due to its 577 µs duration, so the value of the data sheet was used for Scenario 3 to ensure a conservative estimate.

C. GSM Power Architecture Analysis

Integration of the SIM808 module revealed a critical limitation in the power supply. During GSM network registration and SMS transmission, the module draws current in bursts of up to 2 A for approximately 577 µs. Despite the 8.4 V series battery pack and a 1000 µF bulk electrolytic capacitor on the 4.0 V supply rail, these bursts caused brownout resets that prevented successful SMS transmission. The voltage drop across the bulk capacitor during a 2 A, 577 µs burst was calculated as 1.154 V. This reduces the 4.0 V rail to a minimum of 2.846 V, which falls below the 3.4 V operating threshold of SIM808, causing internal reboot and transmission failure. To avoid brownout, the supply voltage must not drop more than 0.6 V, requiring a minimum capacitance of approximately 2000 µF. The installed 1000 µF capacitor is therefore insufficient by a factor of approximately 1.9×. The replacement with a low-ESR 2200 µF capacitor is the identified solution, but space limitations within the current stripboard layout prevented immediate implementation.

D. Cost Analysis

The total production cost of the prototype was £59.49, which is 28% below the £83 target (G3), demonstrating that financially viable mass deployment by non-governmental organisations is technically achievable with the selected component architecture.

V. Conclusion

This paper presented the TMED, a low-cost IoT proof-of-concept prototype designed to detect hypothermia risk in rough sleepers and trigger a dual-stage emergency response. The thermal sensing and local alerting cores met all design targets. The NTC thermistor accurately detected the 5.0°C threshold under simulated field conditions, the local alarm was activated reliably, and all user interface interactions functioned correctly. Empirical runtime measurements confirmed a worst-case operational lifespan of 8.49 days, exceeding the 7-day target by a 21% margin. The total production cost of £59.49 remained 28% below the £83 budget, demonstrating that financially viable deployment by charitable organisations is achievable with this architecture.

The GSM emergency communication path was partially validated. The revised power architecture (two series 18650 Li-Ion cells regulated by an LM2596S step-down converter) successfully sustained the SIM808 module through network registration, confirming that the communication concept is architecturally sound. In this prototype, end-to-end SMS delivery was not achieved because the 1000 µF bulk capacitor on the 4.0 V supply rail was insufficient to buffer the 2 A GSM transmission bursts. Analysis showed that a minimum capacitance of 1923 µF is required; replacing the capacitor with a low-ESR 2200 µF alternative is the next step and represents a straightforward hardware revision.

Future work will prioritise four areas. First, it is to implement the 2200 µF capacitor to fix and validate end-to-end SMS and GPS transmission. Second, conducting a live field trial in collaboration with the DRK Kaltebus Team to evaluate the device under real operational conditions. Third, it is transitioning the communication module from 2G GSM to a modern low-power cellular standard such as NB-IoT or LTE-M, as 2G networks face imminent shutdown in several countries. Fourth, upgrade the acoustic alarm to a higher-decibel model or widen the apertures of the enclosure membrane to ensure that the alarm can reliably wake a sleeping person through heavy winter clothing.

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