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Integration of Iot Temperature Sensors in Plastic-Perlite Bricks for Building Energy Monitoring

Rasika Appaso Kharat[1], Pratiksha Sanjay Mane[2], Parvej Najirhusen Shaikh[3], Dr. S. B. Walke[4]
Department of Civil Engineering
Vidya Pratishthan's Kamalnayan Bajaj Institute of Engineering and Technology (VPKBIET), Vidyanagri, Baramat Savitribai Phule Pune University, Pune, Maharashtra, India

Abstract- The rapid growth of urban infrastructure has increased the demand for energy-efficient and sustainable construction materials. This study focuses on the integration of IoT-based temperature sensors within plastic-perlite composite bricks to enhance building energy monitoring and management. The proposed system utilizes waste plastic as a partial replacement material combined with expanded perlite to develop lightweight, thermally efficient, and eco-friendly building units compatible with standard M20-grade concrete structures. IoT temperature sensors (DS18B20) are embedded within the composite bricks to continuously monitor internal and external temperature variations, enabling real-time data collection and analysis through wireless communication modules. Laboratory tests, including compressive strength, thermal conductivity, and water absorption, are conducted to evaluate the structural and thermal behavior of the developed bricks. The experimental results show that the integration of perlite and waste plastic significantly improves thermal resistance, reduces heat transfer, and decreases structural dead load by lowering the average brick density to 821–907 kg/m^3 compared to 1800 kg/m^3 for conventional units. This research promotes the development of sustainable smart construction materials, aligning with modern green building technologies and the global agenda for energy efficiency.

Keywords: Sustainable Construction, Waste Plastic Recycling, Sand, Expanded Perlite, IoT Temperature Sensors.

I. INTRODUCTION

The construction industry is one of the largest consumers of natural resources and energy worldwide. Rapid urbanization and infrastructure development have significantly increased the demand for conventional construction materials such as cement, concrete, steel, and clay bricks. The production of traditional fired clay bricks is particularly energy-intensive, requiring high-temperature kilns that release substantial volumes of carbon dioxide (CO2), thereby contributing to global warming and climate change.

Concurrently, plastic waste accumulation has emerged as a catastrophic environmental threat. Millions of tonnes of non-biodegradable polymers are landfilled or discharged into ecosystems annually, where they persist for hundreds of years. Recycling waste plastic into structural or partition units offers a dual-benefit strategy: it helps mitigate plastic pollution while conserving finite natural aggregates.

In recent years, lightweight aggregates like expanded perlite have garnered attention due to their highly porous structure and remarkable thermal insulation properties. When blended with recycled plastic binders and sand, perlite minimizes heat transfer across building envelopes. To evaluate these modern composite materials under dynamic environmental contexts, integrating structural components with the Internet of Things (IoT) is vital. This study designs, manufactures, and evaluates a smart hybrid plastic-sand-perlite brick equipped with embedded telemetry nodes for real-time thermal health and efficiency reporting.

II. LITERATURE REVIEW

Sustainable building brick innovations have advanced via independent investigations into lightweight porous fillers and polymeric binder systems. Burgos (2020) characterized raw perlite mineral wastes to manufacture high-durability bricks using a compression unit, proving superior performance over traditional adobe units. Rao and Ram Chandar (2021) examined energy-efficient concrete bricks with partial perlite substitution, establishing an 8% cooling energy reduction inside model structures built with perlite-integrated units.

Polymer modification workflows in masonry manufacturing have similarly shown promise. Parashar (2019) verified that incorporating molten single-use plastic waste at an optimized 30% ratio with industrial quarry dust maximize compressive behavior while radically decreasing moisture absorption metrics. Sahani et al. (2022) studied the physical-mechanical parameters of plastic-sand matrix formulations, determining that a 1:4 plastic-to-sand ratio provides optimal structural binding integrity.

The integration of electronic sensing configurations inside cementitious or structural envelopes represents an emerging vanguard. Dinmohammadi et al. (2025) successfully implemented multi-node telemetry setups featuring DS18B20 digital probes linked via Wi-Fi transmission pipelines to track environmental profiles in housing layouts. Szymczak-Graczyk et al. (2024) validated the use of multi-depth embedded thermal sensors to map moisture-temperature hygrothermal diffusivity coefficients under fluctuating outdoor climates. However, a prominent research gap exists in examining the synchronized physical, mechanical, and dynamic thermal responses of single-unit structural composites fusing polyolefin waste, graded sand, expanded perlite, and permanent internal IoT nodes.

II. MATERIALS AND METHODOLOGY

Material Specifications

The development of the smart composite units involved three primary solid constituents along with specialized digital telemetry hardware:

- **Waste Plastic:** Sourced from local municipal sorting systems containing thermoplastics like Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and Polypropylene (PP). Shredded into 10–20 mm flakes after being washed and oven-dried to prevent fluid vaporization fields.
- **Crushed Sand (M-Sand):** An angular granite aggregate systematically sieved below 4.75 mm to ensure dimensional stability and structural matrix interlocking.
- **Expanded Perlite:** A porous, lightweight siliceous volcanic rock aggregate expanded at temperatures between 850°C and 1100°C, possessing high thermal resistance.
- **IoT Telemetry Probe:** A sealed waterproof DS18B20 digital sensor using a 1-Wire protocol coupled with an ESP32 microprocessor framework to log high-resolution time-series temperature profiles.

Table 1. Physical Properties of Thermoplastic Binders

Property	Low-Density Polyethylene (LDPE)	High-Density Polyethylene (HDPE)	Polypropylene (PP)
Melting Point (°C)	105 – 115	120 – 130	130 – 170
Density (g/cm³)	~0.91	~0.95	~0.90
Tensile Strength (MPa)	10 – 20	20 – 40	25 – 40
Moisture Absorption	Negligible	Negligible	Negligible

Table 2. Physical Properties of Crushed Aggregate (M-Sand) and Expanded Perlite

Property	Crushed Manufactured Sand (M-Sand)	Expanded Perlite Aggregate
Physical Appearance	Angular, rough grey/tan mineral grains	White, ultra-light porous granular sparks
Particle Size Distribution	0.075 mm – 4.75 mm	0.50 mm – 2.00 mm
Bulk Density (kg/m³)	1600 – 1800	30 – 150
Specific Gravity	~2.6 – 2.9	~0.9 – 1.1
Thermal Conductivity (W/m·K)	High (~1.5 – 2.0)	Very Low (0.04 – 0.06)
Water Absorption Capacity	2.0% – 4.0%	200% – 400% (High internal porosity)

Manufacturing Framework
The fabrication sequencing was maintained across specialized batching balances. Plastic fractions were transferred into automated heating pans where thermal thresholds were controlled between 105°C and 115°C to achieve optimal fluid melting without inducing degradation or noxious volatilization cycles. Sifted, pre-heated M-sand was systematically incorporated into the molten polymer liquid, followed by the immediate introduction of the expanded perlite fractions. The aggregate paste was mixed manually to ensure absolute homogeneity. The homogeneous composite paste was cast into standard metallic molds (190 mm × 90 mm × 90 mm) coated with release oils, compacted using normalized tamping rods, and allowed to cool for 6 hours prior to clean demolding.

III. EXPERIMENTAL INVESTIGATION

A total experimental block of 12 bricks was cast to run comparisons against conventional bricks. This included 3 standard Conventional sand brick units and 9 specialized hybrid plastic-perlite brick units distributed uniformly across three distinctive base ratios (M1, M2, and M3). Structural, gravimetric, and hydro-durability parameters were checked under normalized Indian Standard (IS) codes including IS 3495 (Part 1-3) and IS 1077 guidelines.

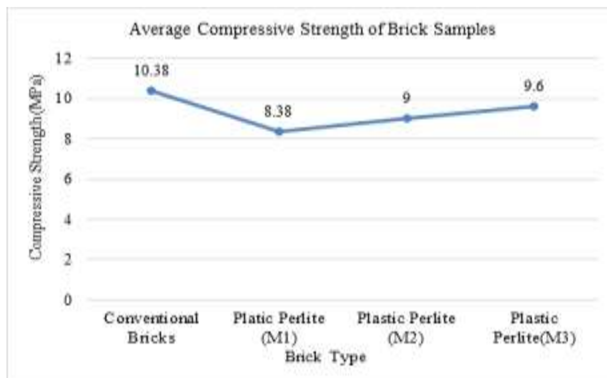
Dynamic thermal insulation logging was completed by tracking heat propagation speeds through the cross-sectional profiles of the units over constant 5-minute laboratory heating cycles using the embedded internal DS18B20 digital sensors.

IV. RESULTS AND DISCUSSION

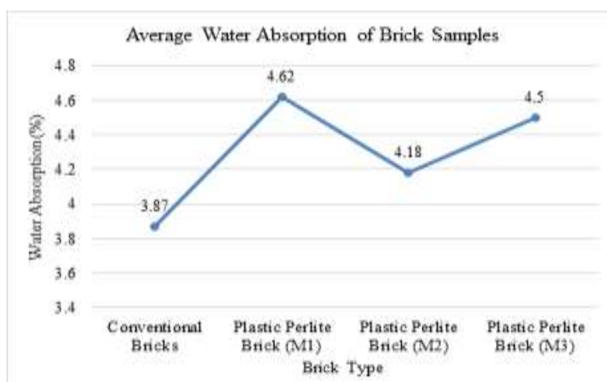
Structural and Gravimetric Responses
The mechanical interactions of the composite bricks show direct dependency on the aggregate formulation balances. Standard fired control bricks demonstrated a reference strength of 10.38 MPa. The plastic-perlite hybrid compositions (M1, M2, M3) exhibited a slight drop in compression limits due to the high internal void configuration of the expanded perlite porogen. However, all variants successfully surpassed the minimum thresholds required under IS structural regulations.

Table 3. Consolidated Mechanical, Gravimetric, and Structural Performance Metrics

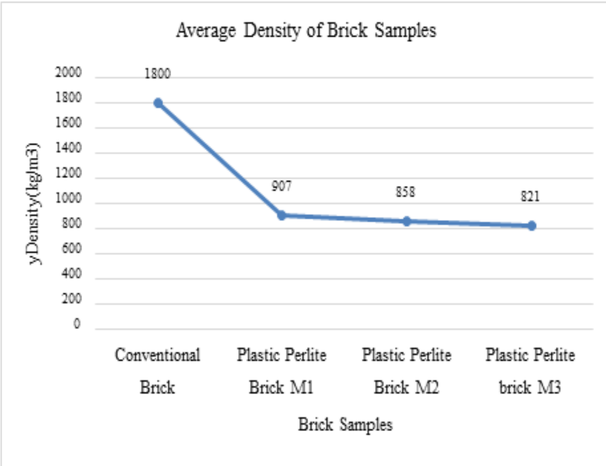
Brick Designation	Mix Ratio (Plastic:Sand: Perlite)	Avg. Compressive Strength (MPa)	Avg. Water Absorption (%)	Avg. Dry Density (kg/m³)
Conventional Brick	100% Clay Refractory Matrix	10.38	3.87%	1800
Plastic Perlite M1	55% : 35% : 5% by weight	8.38	4.62%	907
Plastic Perlite M2	55% : 30% : 10% by weight	9.00	4.18%	858
Plastic Perlite M3	55% : 30% : 15% by weight	9.60	3.79%	821



Graph No. 1. Average Compressive Strength of Brick sample



Graph No. 2. Average Water Absorption of Brick Samples



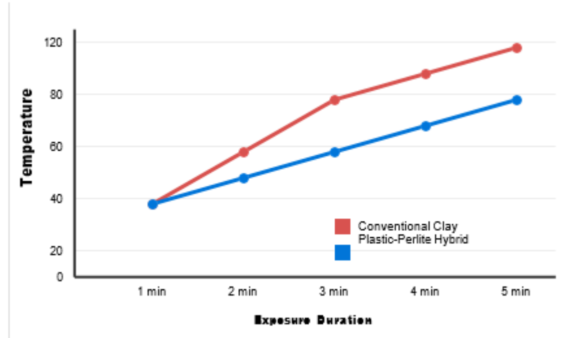
Graph No. 3. Average Density of Brick Samples

The dry density calculations showed a dramatic reduction for the perlite configurations, descending to an average minimum of 821 kg/m³ in the M3 mix. This represents a 54.3% weight reduction relative to traditional units, confirming the material's viability for reducing building dead loads. Water absorption testing revealed exceptionally stable behavior, where all test groups remained well below the 15% first-class brick ceiling. This resistance is attributed to the molten thermoplastic binding matrix, which securely seals internal interstitial void zones against moisture infiltration.

Real-Time IoT Thermal Insulation Performance
The dynamic telemetry logs obtained from the embedded internal sensors during structural heating configurations are summarized in Table 4.

Table 4. Cross-Sectional Internal Temperature Rise Profiles under Exposure

Time Interval (Minutes)	Conventional Clay Brick Core Temp (°C)	Plastic-Perlite Smart Brick Core Temp (°C)
1.0	40.0	40.0
2.0	60.0	50.0
3.0	80.0	60.0
4.0	100.0	70.0
5.0	120.0	80.0



Graph no. 4. Real-Time Core Temperature Rise Profile over Exposure Time

The captured telemetry profiles demonstrate a stark divergence in thermal propagation. While conventional units permit rapid core temperature inflation up to 120°C within 5 minutes, the plastic-perlite smart composite dampens the internal rise to 80°C. This represents a 33.3% structural temperature insulation enhancement. The expanded perlite matrix acts as a localized thermal barrier, demonstrating the material's value for optimizing HVAC loads and improving indoor thermal comfort in energy-efficient green building applications.

V. CONCLUSION AND FUTURE SCOPE

This research successfully developed an eco-friendly, smart structural composite brick using recycled thermoplastic polymers, M-sand, and expanded perlite integrated with permanent internal IoT nodes. Gravimetric and physical characterization confirmed that the smart composite bricks reduce the unit dry dead weight by up to 54.3% compared to classical clay configurations while satisfying structural compression requirements according to IS guidelines.

The embedded digital telemetry system provided accurate real-time logging, showing a 33.3% reduction in internal core heat transfer compared to traditional fired clay units. Future investigations will evaluate long-term weathering degradation kinetics, full-scale structural assembly fire-rating periods, and look to integrate edge-computing frameworks with cloud systems for automated structural health monitoring in smart cities.

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