COMPARATIVE ASSESSMENT OF THERMAL REGULATION CONFIGURATIONS AND DEVELOPMENT OF AN IOT-BASED MONITORING SYSTEM FOR URBAN MINIATURE PROTECTED HOUSES

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Greenhouse microclimate management is critical for tropical crop production, where excessive air temperatures pose significant heat stress risks. Four cooling configurations of fan ventilation with full light (FVFL), fan ventilation with 50% shade (FVPL), passive ventilation with full light (NVFL), and passive ventilation with 50% shade (NVPL) were assessed in single non-replicated 7 ft × 6 ft × 5.5 ft protected houses alongside an outdoor reference (ACOR) at the University of Sri Jayewardenepura, Nugegoda, Sri Lanka (6.87°N, 79.90°E; agro-ecological zone WL1a; 26.5°C mean annual temperature; ~2,387 mm rainfall). A three-node ESP32-based IoT platform monitored microclimate at two-minute intervals using DHT22 sensors at three heights (0.30 m, 1.15 m, 2.00 m), yielding 60,201 records during the January to April 2026 dry inter-monsoon season (ambient: 28.6–32.8°C). One-way ANOVA with Tukey HSD post-hoc comparisons confirmed statistically significant inter-system daytime temperature differences ($F = 1188.4$, $p < 0.001$; $\eta^2 = 0.045$), with all six pairwise contrasts significant at $p < 0.001$. Fan-ventilated systems recorded lower daytime temperatures than passive counterparts (FVFL: 33.53°C vs NVFL: 35.52°C; FVPL: 33.69°C vs NVPL: 35.13°C), achieving cooling benefits of 1.99°C (Cohen's $d = 0.484$) and 1.44°C (Cohen's $d = 0.397$), respectively. All systems exceeded 30°C for 10–11 hours daily; fan systems exceeded 34°C for 6 hours, while in passive systems, exceeded for 7 hours ($p < 0.001$). Vertical stratification was highest in NVPL (TSI = 2.92°C, Cohen's $d = 0.544$), indicating roof-zone heat accumulation under passive shaded conditions. A Random Forest model predicted internal temperature 30 minutes ahead (test $R^2 = 0.818$, RMSE = 1.95°C; cross-validation $R^2 = 0.802 \pm 0.064$), providing an acceptable feasibility benchmark for predictive climate control. These results establish FVPL as the most effective and energy-efficient configuration, demonstrating that structured IoT monitoring combined with machine learning prediction offers a practical pathway for data-driven microclimate management in tropical urban protected agriculture.

Keywords: fan ventilation, greenhouse microclimate, IoT monitoring, Random Forest, shade net, thermal stratification