Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 47 No. 04 (2026)

Thermal Comfort-Based Fan Speed Estimation: A Sensor-Based Approach for Adaptive Indoor Airflow

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Abstract:- This paper presents a sensor-based framework for thermal-comfort assessment and automatic fan-speed estimation using environmental and occupant-related measurements. A DHT22 sensor acquires room temperature and relative humidity, an LM35 provides body-temperature information, and a pulse sensor provides heart-rate data. A NodeMCU is used for ambient-temperature acquisition and communication, while an Arduino UNO performs data acquisition and processing. Required air movement is estimated from the measured thermal condition, and fan speed is related to the airflow requirement using a fan-performance relationship. PMV and PPD are calculated to quantify thermal sensation and dissatisfaction. For the reported test condition of 33 °C ambient temperature and 40.70% relative humidity, the calculated air velocity was 1.21 m/s, the estimated fan speed was 157 rpm, and the reported PMV was 2.8. These results demonstrate the intended sensing-to-comfort computation chain; however, multi-condition testing, sensor calibration, airflow/speed measurement, repeatability, uncertainty analysis, and energy-consumption measurements are required to substantiate closed-loop fan-speed control.

Keywords: Thermal comfort; PMV; PPD; DHT22; LM35; pulse sensor; NodeMCU; Arduino UNO; fan-speed estimation; air velocity.

1. Introduction

Thermal comfort is a central consideration in the design and operation of indoor environments. ANSI/ASHRAE Standard 55 identifies environmental and personal factors that influence thermal comfort, while the PMV/PPD framework provides a standardized analytical approach for evaluating thermal sensation and dissatisfaction [1], [2]. Conventional fan operation commonly relies on manual speed selection or temperature thresholds and may therefore overlook relative humidity, air movement, occupant activity, and clothing level. Recent IoT-based thermal-comfort studies have demonstrated the feasibility of combining low-cost sensors, embedded controllers, and comfort models for indoor monitoring and control [6]–[8].

The present work develops a sensor-integrated framework in which environmental measurements are combined with occupant-related parameters to estimate the required air movement and corresponding fan speed, while PMV and PPD are used as comfort indicators. The architecture uses DHT22, LM35, and pulse sensing together with NodeMCU and Arduino UNO hardware. The work focuses on the measurement, computation, and fan-speed estimation chain; experimental validation of actual fan speed and energy consumption is identified as an essential next step. Adaptive comfort research also indicates that occupant expectations and contextual conditions can influence thermal preference, motivating control strategies that consider more than room temperature alone [4].

A. Research Motivation and Gap

Many low-cost automatic fan systems use only temperature and humidity to modify fan speed, whereas thermal-comfort studies often focus on PMV/PPD assessment without directly connecting comfort information to fan-speed selection. The contribution of the present work is the integration of environmental sensing, occupant-related sensing, IoT-assisted ambient-temperature acquisition, airflow estimation, fan-speed estimation, and PMV/PPD

computation in a single low-cost prototype. The work also identifies the experimental quantities required to validate the proposed sensing-to-actuation chain quantitatively.

2. Proposed Work

Fanger's thermal-comfort framework established the heat-balance basis of the PMV model [3]. Adaptive comfort research subsequently demonstrated that contextual and historical effects can influence occupants' thermal expectations and preferences [4]. PMV-based fuzzy control has been investigated as an alternative to conventional temperature-only HVAC control [5]. IoT architectures have also been applied to indoor thermal-comfort monitoring using Arduino/ESP8266-based sensing and communication [6], [7]. A low-cost IoT platform using Arduino and Raspberry Pi has demonstrated real-time acquisition and PMV/PPD evaluation [8]. Field research in India has examined the relationship between air velocity, ceiling-fan use, thermal comfort, and energy implications [9]. Recent work further reports experimental adaptive fan control in small-scale cooling systems, indicating the potential for energy reduction through adaptive operation [12].

A. System Architecture

The proposed architecture contains four functional layers: sensing, communication/data acquisition, thermal-comfort computation, and fan-speed estimation. The DHT22 provides room temperature and relative humidity. The LM35 provides body-temperature information, while the pulse sensor provides heart-rate information. NodeMCU supplies the ambient-temperature input and communication interface, and the Arduino UNO integrates the sensor values and performs the required calculations. The resulting thermal-comfort indicators are then used to estimate the required air movement and fan speed. The architecture should be interpreted as a computational/control framework; actual fan-speed regulation requires a validated actuator interface and measured fan-speed feedback.

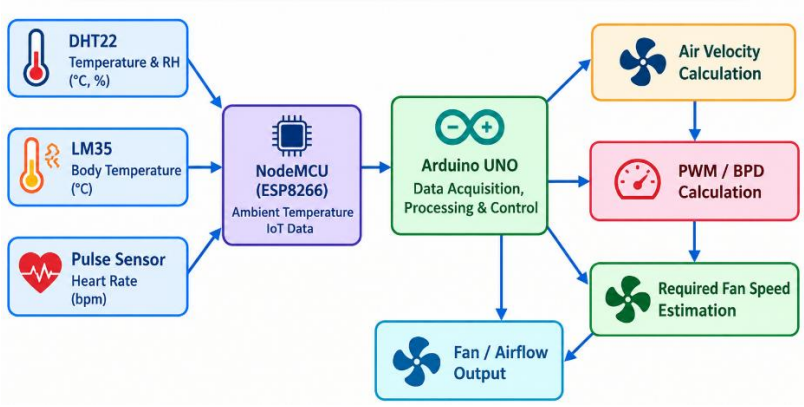


Figure 1. Proposed thermal comfort-based fan control architecture

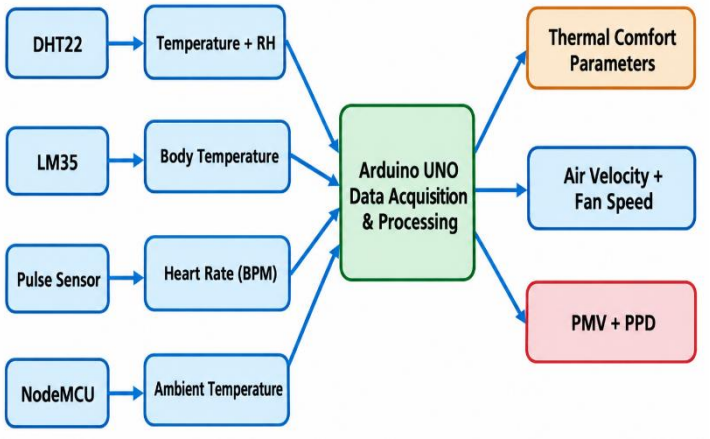


Figure 2. Measurement and signal-flow diagram of the proposed system

3. Hardware Implementation

Table1. Functions of Components

Component	Measured / Processed Variable	Function in Proposed System
DHT22	Temperature and relative humidity	Room/environmental sensing
LM35	Body temperature	Occupant-related thermal information
Pulse sensor	Heart rate / BPM	Activity/metabolic-rate estimation
NodeMCU	Ambient temperature / IoT data	Network-assisted ambient-temperature acquisition
Arduino UNO	Processed sensor data	Data acquisition, calculation and control logic

The DHT22 is used as a digital temperature/humidity sensor, while the LM35 and pulse sensor provide analog sensing signals. The sensors are interfaced with the Arduino UNO for acquisition and processing, while the NodeMCU provides the ambient-temperature/communication input. For journal-level validation, the sensor placement, calibration procedure, sampling interval, ADC/reference configuration, and measurement uncertainty should be explicitly reported. In particular, the LM35 body-temperature measurement requires a defined contact location and calibration procedure.

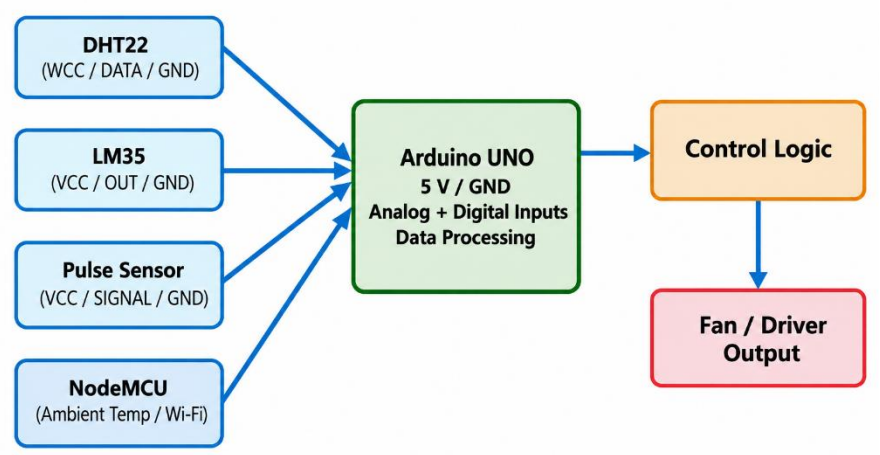


Figure 3. Hardware connection diagram

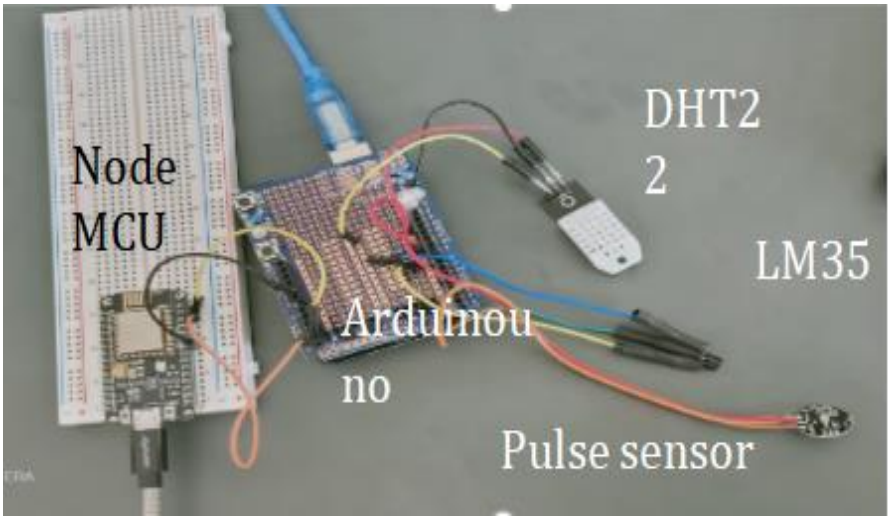


Figure 4. Experimental hardware prototype

4. Mathematical Model and Thermal Comfort Estimation

A. Air-Velocity Estimation

The required air velocity is estimated from ambient temperature and relative humidity using the relationships implemented in the present work. The equations should be verified against the final firmware/source code before submission, and the units and validity range should be stated explicitly.

$$V = (T_a - T_n) / [4.86(0.029 \times RH)]$$

$$T_n = 0.28T_a + 17.9\ °C$$

where V is the estimated air velocity, T_a is the ambient temperature, T_n is the nominal temperature, and RH is the relative humidity. Because this empirical relation is central to the proposed control chain, its source, unit convention, calibration range, and error should be documented in the final manuscript.

B. Fan-Law Relationship

The fan-law relationship is used to relate volumetric flow rate to rotational speed. For geometrically similar operating conditions, the first-order relationship is:

$$Q_2 / Q_1 = N_2 / N_1$$

where Q_1 and Q_2 are volumetric flow rates and N_1 and N_2 are the corresponding fan speeds. The calculated room air velocity should not be equated directly to volumetric flow rate without an appropriate fan/room relationship. Therefore, the mapping from required air velocity to fan speed should be established experimentally using an anemometer and a tachometer, or using a manufacturer fan-performance curve.

C. PMV and PPD

PMV is calculated from the thermal state of the occupant and environment. The implementation considers air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate, clothing insulation, and related heat-transfer terms. PPD is obtained from PMV and expresses the predicted percentage of occupants dissatisfied with the thermal condition. The PMV/PPD calculation should follow the selected edition of ISO 7730 and the assumptions used for metabolic rate, clothing insulation, mean radiant temperature, and air velocity should be reported explicitly [2].

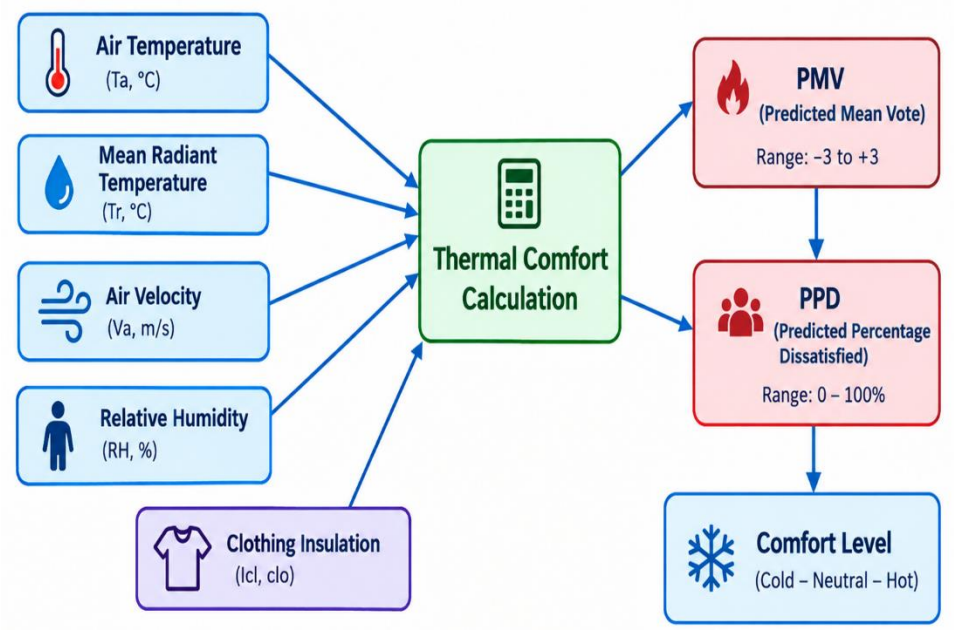


Figure 5. PMV–PPD thermal comfort calculation framework

D. Metabolic Rate

Heart rate is used in the present work as an input for estimating the occupant's activity condition and selecting a corresponding metabolic rate. Because heart rate is influenced by factors other than physical activity, including individual physiology and transient conditions, the heart-rate-to-metabolic-rate mapping should be treated as an estimation model rather than a direct physiological measurement. The mapping, calibration procedure, subject information, and uncertainty should therefore be documented and experimentally validated.

E. Clothing Factor

The clothing factor is selected according to assumed clothing conditions and environmental context. For reproducible PMV calculations, the clothing insulation value (clo) should be stated numerically for every test condition rather than inferred only from temperature categories. Where possible, the final system should allow the user to specify clothing level or use a documented validated estimation procedure.

5. Proposed Control Methodology

The operating sequence begins with system initialization and sensor acquisition. Ambient temperature is obtained from the NodeMCU input when available; otherwise, the DHT22 room-temperature value is used. Relative humidity is obtained from the DHT22. Heart rate is acquired from the pulse sensor and body temperature from the LM35. These measurements are processed to estimate metabolic rate and thermal-comfort parameters. The required air velocity and corresponding fan speed are then calculated, followed by PMV and PPD estimation. For true automatic fan control, the estimated speed should be converted into an actuator command and compared with measured fan speed through a feedback loop; the present manuscript reports the sensing and estimation stage.

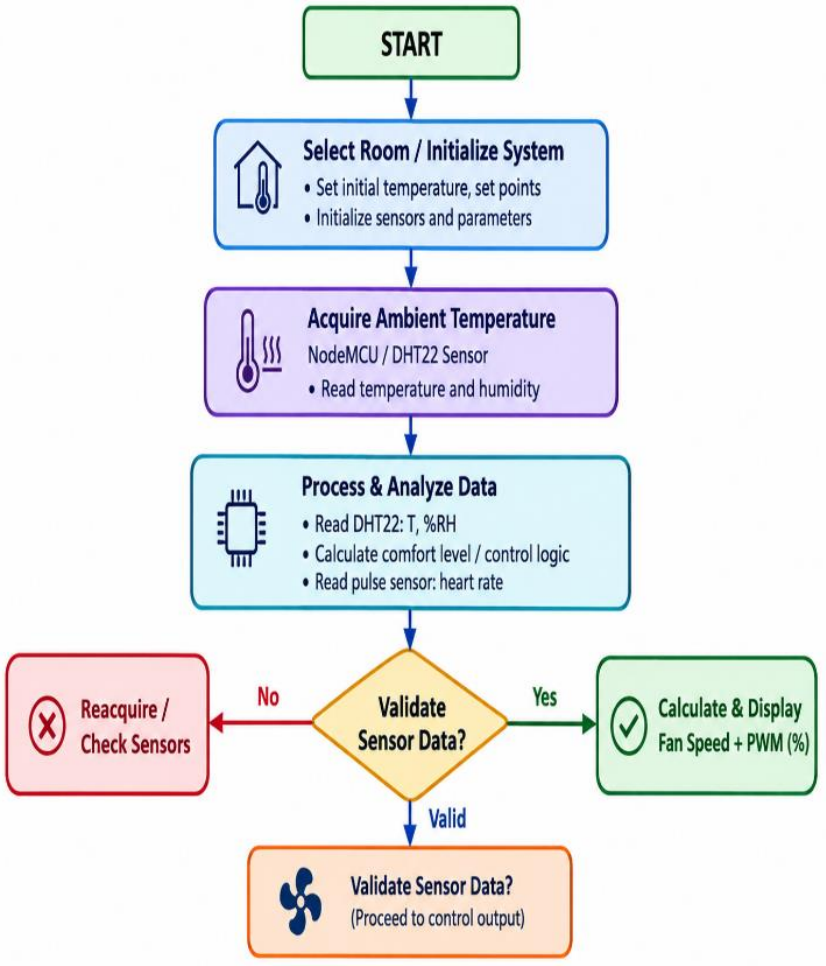


Figure 6. Proposed control methodology flowchart

6. Results and Discussion

The prototype shown in Figure 4 integrates the sensing modules and controllers on a common hardware platform. The serial-monitor output in Figure 7 reports continuous estimation of fan speed and PMV while the system is active.

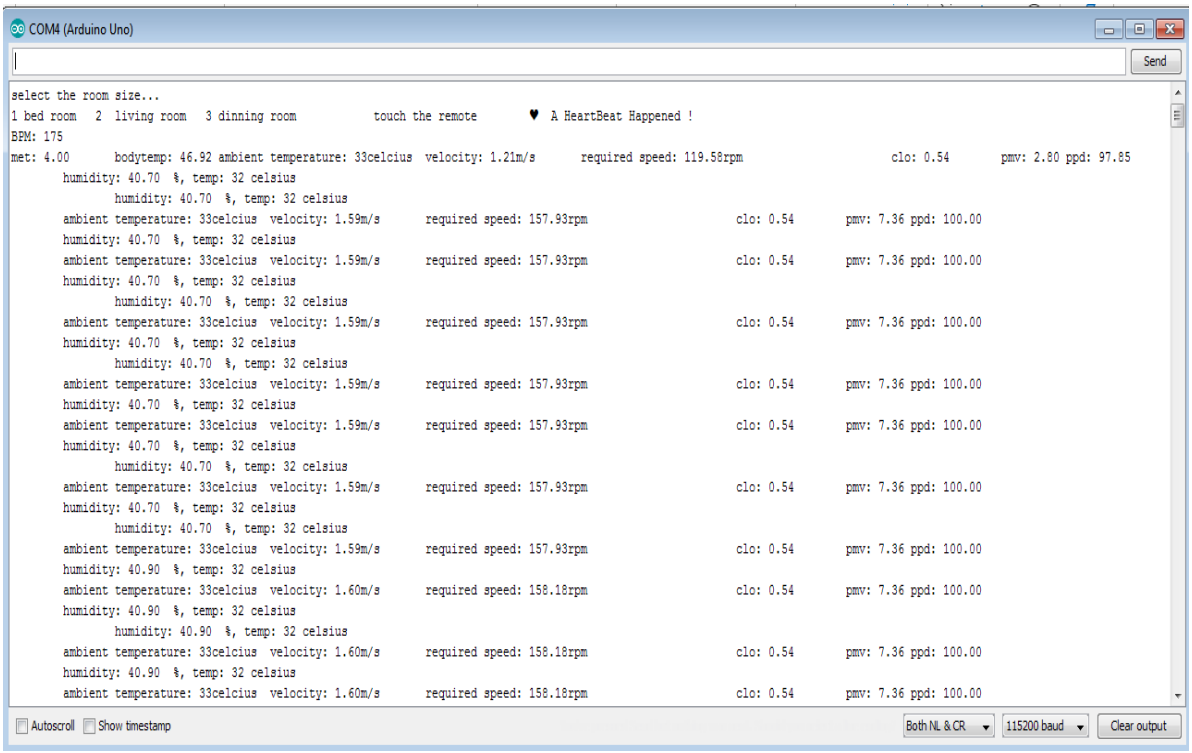


Figure 7. Experimental serial-monitor output for fan-speed and PMV calculation

Table 2. Reported values from the outputs

Parameter	Reported value
Heart rate	175 bpm
Metabolic rate	4.00 met
Body temperature	96.5 (unit to be verified)
Ambient temperature	33 °C
Relative humidity	40.70 %
Air velocity	1.21 m/s
Required fan speed	157 rpm
PMV	2.8
PPD corresponding to PMV = 2.8	≈ 97.8%*

For the reported test condition of 33 °C ambient temperature and 40.70% relative humidity, the calculated air velocity was 1.21 m/s and the estimated fan speed was 157 rpm. The reported PMV was 2.8, corresponding to approximately 97.8% PPD when the standard PMV–PPD relationship is applied. These values demonstrate the intended computational chain: environmental sensing → airflow estimation → fan-speed estimation → PMV/PPD evaluation. The PPD value should be recalculated from the final validated PMV implementation before publication.

The present experimental evidence is limited to a single reported operating condition. A journal submission should include multiple combinations of temperature, relative humidity, occupant activity, and clothing level; repeated measurements; sensor calibration and uncertainty; measured air velocity; measured fan speed; and power consumption. A comparison between commanded/estimated speed and measured speed should be reported using absolute error, mean absolute error (MAE), and/or root-mean-square error (RMSE). Energy consumption should also be compared with a conventional fixed-speed or temperature-threshold strategy if an energy-efficiency claim is made.

The reported body-temperature value of 96.5 °C in the source output is not physically plausible and must not be presented as a validated physiological measurement. In the revised table it is therefore marked 'unit to be verified'. If the original firmware output was 96.5 °F, the corresponding value would be approximately 35.8 °C; this conversion must be confirmed from the firmware and measurement protocol before the value is used in the PMV calculation. The final paper should report the corrected value, sensor conversion equation, sensor placement, calibration method, and measurement uncertainty.

Table 3. Proposed Approach of the work

Aspect	Conventional fan control	Proposed approach
Primary input	Temperature / manual setting	Temperature + RH + occupant-related parameters
Airflow	Fixed or manually selected	Calculated from thermal condition
Fan speed	Preset / threshold	Estimated using fan-law relationship
Thermal comfort	Usually indirect	PMV and PPD
Occupant activity	Generally not included	Heart-rate-based estimation
IoT capability	Not necessarily available	NodeMCU-assisted ambient-temperature acquisition
Validation	Often limited to temperature response	Requires measured airflow, speed, repeatability and energy validation

7. Experimental Validation and Control Implementation Requirements

This paper presents a sensor-integrated framework for thermal-comfort assessment and fan-speed estimation using DHT22, LM35, pulse sensing, NodeMCU, and Arduino UNO hardware. Environmental and occupant-related parameters are processed to estimate required air movement and fan speed, while PMV and PPD provide thermal-comfort indicators. Under the reported test condition, the system produced an estimated air velocity of 1.21 m/s, fan speed of 157 rpm, and PMV of 2.8. The prototype therefore demonstrates the feasibility of the proposed sensing-to-computation chain. However, the present evidence does not yet establish generalized closed-loop fan-speed control. Sensor calibration, multi-condition and repeated experiments, measured airflow and fan-speed validation, uncertainty analysis, and energy-performance comparison are required before strong claims of control accuracy or energy savings can be made.

8. Conclusion

This paper presents an updated journal-style formulation of a thermal comfort-based automatic fan-speed control system. The system combines DHT22, LM35 and pulse sensing with Node MCU and Arduino UNO processing. Environmental and occupant-related parameters are used to estimate required air velocity and fan speed, while PMV and PPD provide thermal-comfort indicators. The reported prototype demonstrates feasibility of the concept under the tested condition. To establish a publishable experimental contribution, the next stage should focus on sensor calibration, multi-condition testing, measured airflow/speed validation and energy-performance comparison.

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