



## Design and Implementation of a Low-Cost Infrared Remote Controlled AC Fan Speed Regulator Using NE555 and CD4017B Logic

A. J. Onogwu<sup>1</sup>, O. U. Okporie<sup>2</sup>, <sup>1,2,5</sup> Department of Electrical and Electronic Engineering Technology, Federal Polytechnic, Ohodo Enugu, Nigeria  
A. I. Akor<sup>3</sup>, A. J. John<sup>4</sup>, and I. Akogwu<sup>5</sup>  
<sup>3</sup> Department of Electrical and Electronic Engineering Technology, Kaduna Polytechnic, Kaduna, Nigeria  
<sup>4</sup> Department of Electrical and Electronic Engineering Technology, Eastern Polytechnic, Port Harcourt, Nigeria

### Abstract

Manual fan regulators require physical access and rely on mechanical contacts. This paper presents a low-cost infrared remote-controlled regulator for a tapped single-phase AC fan using two NE555 timers, a CD4017B one-hot counter, a 38 kHz infrared receiver, optotriac isolation, and TRIAC switching. The supplied prototype was re-engineered into a calculation-verified design while preserving its discrete, firmware-free architecture. The transmitter timing network was corrected to  $R_A = 1\text{ k}\Omega$ ,  $R_B = 18\text{ k}\Omega$ , and  $C = 1\text{ nF}$ , which gives a calculated carrier frequency of 38.9 kHz and a duty cycle of 51.4%. Receiver command conditioning uses  $R = 100\text{ k}\Omega$  and  $C = 10\text{ }\mu\text{F}$ , which gives a 1.10 s pulse. The full-wave supply analysis was corrected for 50 Hz mains, and a 4700  $\mu\text{F}$  reservoir capacitor is recommended to control ripple. The CD4017B provides four deterministic states: OFF, low, medium, and high. Analytical plots quantify carrier detuning, monostable timing variation, and supply ripple. Functional observations in the source report approximately 10 m line-of-sight operation and about 1 s response. The design offers low component cost, electrical isolation, repairability, and no dependence on software or internet services. Its present limitations include the absence of coded addressing, closed-loop speed feedback, harmonic measurements, motor speed data, and long-duration thermal tests.

**Keywords:** *CD4017B, fan speed control, infrared remote control, NE555, optotriac, solid-state switching, TRIAC.*

## I. Introduction

Electric fans remain a practical means of improving perceived thermal comfort in homes, offices, classrooms, and workshops. Recent studies show continuing interest in occupant-controlled air movement, connected fan systems, and low-power personal comfort devices [6], [8], [13]-[16]. The control method therefore affects convenience, energy use, maintainability, and user acceptance.

Many low-cost fans still use a wall-mounted stepped regulator. The user must approach the control point, mechanical contacts wear with repeated operation, and the installation offers no accessibility support for users with restricted mobility. Infrared control removes the physical-access constraint while retaining a simple local command path. Earlier fan-regulator studies developed discrete remote topologies [1] and expanded the control function to include bidirectional operation [2]. Smart-home research now combines infrared links, network gateways, sensing, and predictive control [3], [4], [10]-[17]. Those systems provide richer functions, but they also introduce firmware, network configuration, data management, and higher repair complexity.

This work focuses on a repairable, firmware-free alternative. A push-button transmitter emits a 38 kHz infrared burst. A tuned receiver demodulates the burst, a monostable stage converts it into one clean clock pulse, and a CD4017B advances through four one-hot states. Three states energize separate optotriac and TRIAC channels connected to the fan speed taps, while one state keeps the fan off. The main contributions are the correction of the original timing and power-supply calculations, explicit equation-based component selection, analytical sensitivity graphs, separation of observed results from calculated results, and integration of safety requirements for a mains-connected prototype.

## II. Related Work And Design Position

Research on fan control spans discrete regulators,

microcontroller systems, connected appliances, and occupant-centric comfort control. Madueme et al. [1] presented a sustainable remote-controlled fan regulator for settings where cost and maintainability matter. Anyaka et al. [2] extended AC fan control to speed and direction. Lin et al. [3] developed and verified a smart remote-control platform for household appliances. These studies establish the value of remote command interfaces, but their design objectives differ in complexity, communication architecture, and controlled load.

Recent building research links user-controlled air movement with thermal satisfaction and lower cooling demand [5], [6], [8], [14], [15]. Sensor nodes and IoT platforms now record temperature, humidity, occupancy, fan state, and energy variables [7], [9], [10], [12], [16], [17]. These developments support adaptive and data-driven control, yet they do not eliminate the need for low-cost standalone controllers in locations where network access, software maintenance, or specialized components are undesirable.

The proposed design occupies this low-complexity segment. It does not compete with closed-loop BLDC or AIoT fan controllers. It provides deterministic four-state operation with standard components, local IR control, electrical isolation, and direct compatibility with a conventional tapped AC fan. The design therefore prioritizes serviceability and component availability over telemetry, adaptive control, and remote internet access.

**TABLE I**  
**DESIGN SPECIFICATION**

| Design quantity | Target or selected value                       |
|-----------------|------------------------------------------------|
| Mains input     | 230 V rms, 50 Hz                               |
| Control supply  | 9 V regulated logic rail, 5 V IR-receiver rail |
| IR carrier      | 38 kHz nominal                                 |

| Design quantity              | Target or selected value                              |
|------------------------------|-------------------------------------------------------|
| Command pulse                | Approximately 1.1 s                                   |
| Control states               | OFF, LOW, MEDIUM, HIGH                                |
| Reported line-of-sight range | Approximately 10 m                                    |
| Isolation                    | Optical isolation between logic and mains             |
| Load interface               | Three fan taps switched by independent TRIAC channels |

### III. System Architecture And Operation

#### A. Transmitter

The handheld transmitter uses a 9 V battery, a push button, an NE555 astable oscillator, an NPN transistor, and an infrared LED. Pressing the button powers or enables the oscillator. The transistor supplies the pulsed LED current without loading the timer output. The carrier is selected near 38 kHz to match a TSOP38238-class receiver [18], [20].

#### B. Receiver and Pulse Conditioning

The IR module rejects much of the ambient optical background and produces an active-low digital output when a valid carrier burst is detected. A second NE555 operates as a monostable. It converts a received burst into one pulse of controlled duration, reduces the effect of switch bounce and burst irregularity, and prevents multiple counts during a single command. Supply decoupling is placed at each integrated circuit and directly across the IR module supply pins.

#### C. State Sequencing

The monostable output clocks the CD4017B on its positive transition. Q0 represents OFF. Q1, Q2, and Q3 drive the low, medium, and high speed channels. Q4 is

connected to RESET, so the next command returns the counter to Q0. Since only one decoded output is high at a time, the logic provides one-hot selection and prevents simultaneous steady-state activation of multiple speed taps [19].

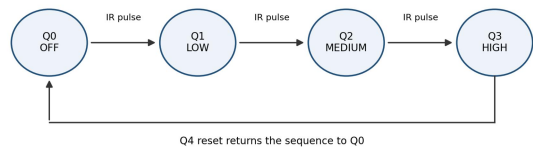


Fig. 2. Four-state command sequence produced by the CD4017B. Q4 generates an immediate reset after the HIGH state.

#### D. Isolated Mains Interface

Each active speed output drives an indicator LED and an optotriac input through a current-limiting resistor. The optotriac provides galvanic isolation and triggers a mains-rated TRIAC connected to one fan tap. A random-phase MOC3022M is compatible with the source topology [21]. For full-cycle tap switching, a zero-cross optotriac is preferable where the motor network permits it, because switching near a voltage zero reduces transients. The TRIAC requires adequate repetitive off-state voltage, surge-current rating, commutation margin, and heat dissipation [22].

### IV. Engineering Design And Calculations

#### A. NE555 Astable Carrier

For the standard NE555 astable connection, the capacitor charge time, discharge time, oscillation frequency, and duty cycle are [18]

$$t_H = 0.693 (R_A + R_B)C \tag{1}$$

$$t_L = 0.693 R_B C \tag{2}$$

$$f_c = \frac{1}{[0.693 (R_A + 2R_B)C]} \approx \frac{1.44}{[(R_A + 2R_B)C]} \tag{3}$$

$$D = \frac{(R_A + R_B)}{(R_A + 2R_B)} \quad (4)$$

The source listed  $R_A = 100 \Omega$ ,  $R_B = 220 \Omega$ , and  $C = 0.1 \mu F$ . Substitution into (3) gives about 25.9 kHz rather than the stated 39 kHz. A corrected practical set is  $R_A = 1 k\Omega$ ,  $R_B = 18 k\Omega$ , and  $C = 1 nF$ . These values give  $t_H = 13.17 \mu s$ ,  $t_L = 12.47 \mu s$ ,  $f_c = 38.9 kHz$ , and  $D = 51.4\%$ . A 1% resistor network and a 5% C0G or film capacitor are recommended because carrier error is dominated by timing-component tolerance.

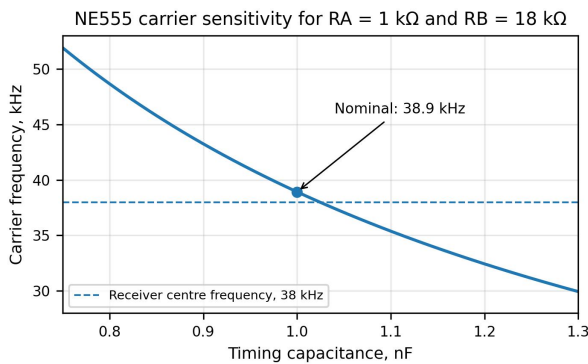


Fig. 3. Calculated carrier-frequency sensitivity to timing capacitance. The nominal component set produces 38.9 kHz.

## B. Infrared LED Driver

A transistor driver separates the timer from the pulsed optical load. The LED resistor is selected from

$$R_{LED} = \frac{(V_{CC} - V_F - V_{CE(sat)})}{I_{LED}} \quad (5)$$

For  $V_{CC} = 9 V$ ,  $V_F = 1.2 V$ ,  $V_{CE(sat)} = 0.2 V$ , and a 42 mA pulse current,  $R_{LED}$  is approximately  $181 \Omega$ . A standard  $180 \Omega$  resistor is suitable after confirmation against the chosen LED pulse-current rating. The transistor base resistor must provide adequate forced gain while keeping the NE555 output current within its data-sheet limit.

## C. Receiver Power Supply

A 230/12 V isolating transformer, full-wave bridge, reservoir capacitor, and linear regulators supply the

receiver. The bridge output peak and ripple frequency are

$$V_{PK} \approx \sqrt{2} V_{S(rms)} - 2V_D \quad (6)$$

$$f_r = 2 f_m = 100 \text{ Hz for a } 50 \text{ Hz mains supply} \quad (7)$$

With  $V_S = 12 V$  rms and  $V_D \approx 0.7 V$  per conducting diode,  $V_{PK}$  is approximately 15.6 V. The first-order reservoir ripple is

$$\Delta V_{PP} \approx \frac{I_L}{(f_r C_R)} \quad (8)$$

At  $C_R = 4700 \mu F$ , the calculated ripple is 0.213 V at 100 mA and 1.064 V at 500 mA. By comparison, the source value of about  $400 \mu F$  gives 2.5 V at 100 mA and 12.5 V at 500 mA. The larger capacitor therefore provides the required regulator headroom. A 25 V voltage rating is selected above the no-load rectified peak.

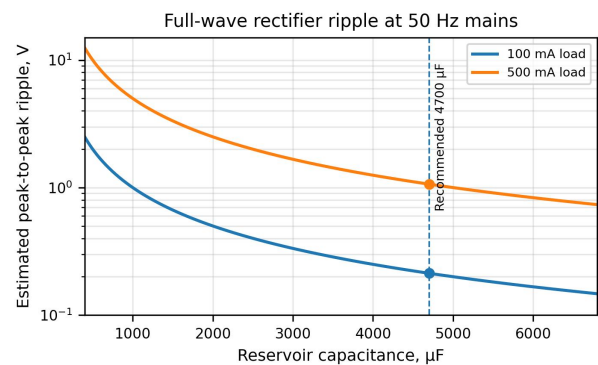


Fig. 4. Calculated reservoir ripple versus capacitance on a logarithmic voltage scale. The 4700  $\mu F$  selection gives useful margin at 50 Hz mains.

The approximate 7809 dissipation is

$$P_{REG} \approx (V_{IN(avg)} - 9) I_L \quad (9)$$

At an average regulator input near 15.4 V and 100 mA load, dissipation is about 0.64 W. A heat sink or a lower-loss preregulator is required if the load current rises. The 38 kHz IR module should receive a dedicated regulated 5 V rail rather than relying only on a Zener

shunt, because supply noise directly affects receiver reliability.

D. Monostable Command Pulse

For the NE555 monostable, pulse width is [18]

$$T_p = 1.1 R_M C_M \tag{10}$$

Selecting  $R_M = 100\text{ k}\Omega$  and  $C_M = 10\text{ }\mu\text{F}$  gives  $T_p = 1.10\text{ s}$ , which agrees with the approximate 1 s response reported for the prototype. An electrolytic capacitor with  $\pm 20\%$  tolerance produces a broad timing interval. A lower-tolerance capacitor or a smaller capacitor combined with a larger resistor improves repeatability, subject to leakage-current limits.

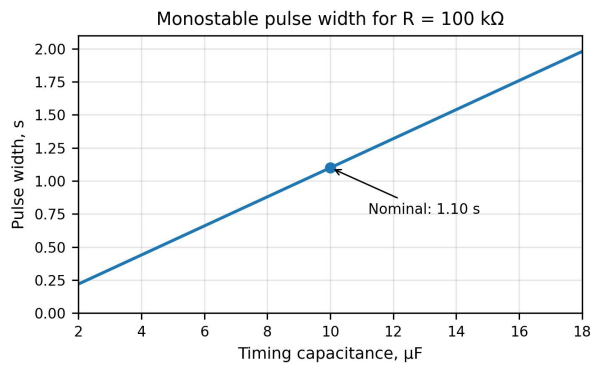


Fig. 5. Calculated monostable pulse width versus timing capacitance for  $R = 100\text{ k}\Omega$ .

E. Counter Logic

Let  $s_k$  denote the commanded state after the  $k$ th valid IR pulse, with OFF = 0, LOW = 1, MEDIUM = 2, and HIGH = 3. The sequence is represented by

$$s_{k+1} = (s_k + 1) \bmod 4 \tag{11}$$

The physical CD4017B implementation uses Q4 to force RESET rather than a binary modulo operator. The one-hot outputs remove the need for a decoder and preserve the selected state between commands. Power-on reset is added with an RC network or supervisor so the fan starts in OFF after supply restoration.

TABLE II  
CORRECTED COMPONENT SELECTION

| Function              | Recommended selection                                                           | Engineering basis                                   |
|-----------------------|---------------------------------------------------------------------------------|-----------------------------------------------------|
| IR carrier timer      | NE555, $R_A = 1\text{ k}\Omega$ , $R_B = 18\text{ k}\Omega$ , $C = 1\text{ nF}$ | 38.9 kHz<br>calculated carrier                      |
| IR emitter driver     | 2N2222A-class NPN, $180\text{ }\Omega$ LED resistor                             | About 42 mA<br>pulse current for stated assumptions |
| IR receiver           | TSOP38238-class module                                                          | 38 kHz<br>demodulating receiver                     |
| Pulse conditioner     | NE555, $100\text{ k}\Omega$ , $10\text{ }\mu\text{F}$                           | 1.10 s calculated pulse                             |
| State controller      | CD4017B, Q4 to RESET                                                            | OFF plus three one-hot speed outputs                |
| Reservoir capacitor   | $4700\text{ }\mu\text{F}$ , 25 V                                                | Ripple margin at 50 Hz mains                        |
| Logic regulator       | 7809 with thermal design                                                        | 9 V timer and counter rail                          |
| IR receiver regulator | Dedicated 5 V regulator                                                         | Stable low-noise receiver supply                    |
| Isolation driver      | MOC3022M or suitable zero-cross equivalent                                      | Logic-to-mains isolation                            |
| Power switch          | 600 V snubberless TRIAC, current-rated for fan                                  | Inductive AC load switching                         |

## V. Prototype Construction And Test Method

The source prototype was assembled first on a breadboard and then on Vero board. Continuity, connectivity, capacitance, resistance, current, and voltage were checked block by block before complete operation. The remote was pointed toward the receiver while the command button was pressed. The reported receiver responded within the operating range and advanced the fan through its speed states.

A journal-grade verification sequence should separate low-voltage and mains testing. First, energize the logic from an isolated bench supply and confirm 38 kHz carrier frequency, IR burst amplitude, receiver output polarity, 1.1 s monostable pulse, and the Q0 to Q3 sequence with an oscilloscope or logic analyzer. Second, connect indicator lamps or isolated dummy loads in place of the fan taps. Third, complete the mains test through an isolation transformer, residual-current protection, fuse, and enclosed terminals. Measure fan-tap voltage, input current, real power, power factor, rotational speed, acoustic response, TRIAC temperature, and repeated-command reliability.

Range testing should be repeated at fixed distances and viewing angles under low, medium, and strong ambient light. At least 30 commands per point should be recorded so command success rate and confidence intervals can be reported. Thermal testing should run each speed for sufficient time to reach steady temperature. Conducted and radiated disturbance should also be assessed before product deployment.

TABLE III  
TRACEABILITY OF PERFORMANCE  
EVIDENCE

| Test variable               | Status in supplied record      |
|-----------------------------|--------------------------------|
| Line-of-sight control range | Reported as approximately 10 m |

| Test variable                               | Status in supplied record                          |
|---------------------------------------------|----------------------------------------------------|
| Response time                               | Reported as approximately 1 s                      |
| State progression                           | Functionally observed across three speed positions |
| Carrier frequency measurement               | Not reported as an oscilloscope trace              |
| Motor speed in r/min                        | Not reported                                       |
| Input power and power factor                | Not reported                                       |
| Command success rate                        | Not reported                                       |
| TRIAC thermal rise                          | Not reported                                       |
| Harmonics and electromagnetic compatibility | Not reported                                       |
| Electrical safety certification             | Not reported                                       |

## VI. Results And Discussion

### A. Functional Performance

The available prototype record supports three functional findings. First, the receiver-transmitter pair operated at a reported maximum line-of-sight distance of approximately 10 m. Second, the command path produced an observed response near 1 s. Third, repeated commands changed the selected fan speed and preserved the selected state until another command arrived. These findings demonstrate functional feasibility, but they do not constitute a full statistical performance dataset.

### B. Analytical Verification

The corrected carrier calculation is the main design correction. The original component set gives about 25.9

kHz and is poorly matched to a 38 kHz receiver. The revised set gives 38.9 kHz, a 0.9 kHz positive offset from nominal. Figure 3 shows the inverse relationship between timing capacitance and carrier frequency. A  $\pm 5\%$  capacitor tolerance changes the calculated frequency to approximately 37.1-41.0 kHz, so component quality affects optical-link margin.

The 1.10 s monostable result agrees with the reported response order, but it also creates deliberate command latency. A shorter pulse between 100 and 300 ms would produce a faster user interface if the received burst is already clean. The selected value is defensible for a simple prototype because it strongly suppresses repeated counts, yet it should be optimized from measured burst duration and user testing.

The power-supply correction is equally important. Nigeria and many other regions use 50 Hz mains, so a full-wave bridge produces a 100 Hz ripple. The original 120 Hz assumption understates required capacitance. Figure 4 shows that 4700  $\mu\text{F}$  materially reduces ripple. The regulator thermal estimate also shows why the control load must be measured rather than assumed. Excessive linear-regulator dissipation reduces reliability and requires a heat sink or switching preregulator.

### C. Reliability, Safety, and Electromagnetic Compatibility

The control board operates near hazardous mains voltage. A deployable version requires a fused input, flame-retardant enclosure, strain relief, protected terminals, adequate clearance and creepage, isolation-slot control, surge suppression, and verified insulation. Fan appliances and their controls should be designed and tested against IEC 60335-1, IEC 60335-2-80, and IEC 60730-1 requirements [23]-[25]. Optical isolation does not by itself make a layout safe. PCB geometry, transformer construction, wiring, enclosure, and protective devices remain decisive.

TRIAC switching of an inductive motor can produce

commutation stress and electromagnetic interference. Each channel should use a suitable RC snubber where required by the selected TRIAC and motor, a metal-oxide varistor across the supply, and a gate network based on the optotriac application circuit. A zero-cross driver reduces turn-on transients for stepped full-cycle switching, while a random-phase driver is necessary only when phase-angle control is intended. The present architecture selects fan taps and therefore does not require phase-angle firing.

### D. Comparison with Contemporary Smart-Fan Research

Contemporary fan research emphasizes sensing, cloud data, AIoT control, and thermal-comfort optimization [10], [13]-[17]. Those functions support adaptive operation and quantitative energy analysis. The present design offers fewer functions, but it has lower software dependence, deterministic behavior, no user-data collection, and direct field repair with standard components. Its strongest application is a low-cost retrofit or teaching platform. Its weakest point is the absence of feedback. The controller commands a tap but does not verify actual rotational speed, stalled-rotor condition, or load current.

## VII. Limitations And Future Development

Future work should use an encoded IR protocol to reject commands from unrelated remotes, a microcontroller or hardware decoder for address validation, zero-cross tap transfer, current sensing for stalled-rotor protection, rotational-speed feedback, and nonvolatile state management where appropriate. A second development path is a connected BLDC fan controller with temperature and humidity sensing, energy logging, and occupant-adaptive control. Such a system should preserve local manual control and safe operation when network services are unavailable.

## VIII. Conclusion

A low-cost infrared remote-controlled AC fan regulator has been organized into a calculation-verified engineering design. The architecture uses an NE555 transmitter, 38 kHz IR receiver, NE555 pulse conditioner, CD4017B one-hot state controller, optotriac isolation, and independent TRIAC channels for three fan taps. Corrected values produce a 38.9 kHz carrier and a 1.10 s command pulse. Corrected 50 Hz supply analysis supports a 4700  $\mu$ F reservoir capacitor and identifies

linear-regulator heat as a design constraint. The supplied prototype reports approximately 10 m line-of-sight range and about 1 s response. The design is suitable for low-cost automation and engineering instruction after completion of mains-safety, thermal, power-quality, and repeated-command tests.

## Acknowledgment

The authors acknowledge the departments and technical personnel who supported component selection, prototype assembly, and functional testing.

## References

1. V. C. Madueme, J. M. Mbunwe, U. B. Akuru, and B. O. Anyaka, "Design topology of a sustainable remote-controlled fan regulator for developing countries," *Renewable and Sustainable Energy Reviews*, vol. 71, pp. 639-644, 2017, doi:10.1016/j.rser.2016.12.090.
2. B. O. Anyaka, P. C. Ene, A. C. Fortune, L. U. Omeje, and K. C. Chijioke, "Design topology of a remote-controlled bi-directional rotation of an A.C. fan with speed control," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 2, pp. 1885-1892, 2020, doi: 10.11591/ijece.v10i2.pp1885-1892.
3. Y.-N. Lin, S.-K. Wang, C.-Y. Yang, V. R. L. Shen, T. T.-Y. Juang, and W.-H. Hung, "Development and verification of a smart remote control system for home appliances," *Computers & Electrical Engineering*, vol. 88, Art. no. 106889, 2020, doi: 10.1016/j.compeleceng.2020.106889.
4. G. H. Merabet et al., "Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques," *Renewable and Sustainable Energy Reviews*, vol. 144, Art. no. 110969, 2021, doi: 10.1016/j.rser.2021.110969.
5. B. Grassi, E. A. Piana, A. M. Lezzi, and M. Pilotelli, "A review of recent literature on systems and methods for the control of thermal comfort in buildings," *Applied Sciences*, vol. 12, no. 11, Art. no. 5473, 2022, doi: 10.3390/app12115473.
6. L. Caruggi de Faria, M. de Andrade Romero, C. Porras-Amores, L. F. de Souza Pirró, and P. Villoria Saez, "Prediction of the impact of air speed produced by a mechanical fan and operative temperature on the thermal sensation," *Buildings*, vol. 12, no. 2, Art. no. 101, 2022, doi: 10.3390/buildings12020101.
7. C. B. D. Kuncoro, A. F. Permana, M. B. Z. Asyikin, and C. Adristi, "Smart wireless climate sensor node for indoor comfort quality monitoring application," *Energies*, vol. 15, no. 8, Art. no. 2939, 2022, doi: 10.3390/en15082939.
8. S. Gokarakonda, C. A. van Treeck, R. Rawal, et al., "Investigating optimum cooling set point temperature and air velocity for thermal comfort and energy conservation in mixed-mode buildings in India," *Energies*, vol. 15, no. 6, Art. no. 2259, 2022, doi: 10.3390/en15062259.
9. B. Sahoh, M. Kliangkhlao, and N. Kittiphattanabawon, "Design and development of Internet of Things-driven

- fault detection of indoor thermal comfort: HVAC system problems case study,” *Sensors*, vol. 22, no. 5, Art. no. 1925, 2022, doi: 10.3390/s22051925.
10. H. R. Khan, M. H. bin Khalid, U. Alam, M. Atiq, U. Qidwai, and S. A. Qazi, “Dataset of usage pattern and energy analysis of an Internet of Things-enabled ceiling fan,” *Data in Brief*, vol. 46, Art. no. 108900, 2023, doi: 10.1016/j.dib.2023.108900.
11. S. Erişen, “A systematic approach to optimizing energy-efficient automated systems with learning models for thermal comfort control in indoor spaces,” *Buildings*, vol. 13, no. 7, Art. no. 1824, 2023, doi: 10.3390/buildings13071824.
12. L.-A. El-Leathay, P. Anghelita, A.-I. Constantin, G. Circiumaru, and R.-A. Chihaiia, “System for indoor comfort and health monitoring tested in office building environment,” *Applied Sciences*, vol. 13, no. 20, Art. no. 11360, 2023, doi: 10.3390/app132011360.
13. Q. Zheng, X. Zhou, X. Li, Y. Liang, B. Cao, Y. He, P. Li, and M. Luo, “Usage behavior and comfort effects of IoT-connected personalized environmental control systems,” *Journal of Building Engineering*, vol. 98, Art. no. 111487, 2024, doi: 10.1016/j.jobbe.2024.111487.
14. R. Risetto and M. Schweiker, “Exploring information and comfort expectations related to the use of a personal ceiling fan,” *Buildings*, vol. 14, no. 1, Art. no. 262, 2024, doi: 10.3390/buildings14010262.
15. M. André, S. Schiavon, and R. Lamberts, “Implementation of desk fans in open office: Lessons learned and guidelines from a field study,” *Building and Environment*, vol. 259, Art. no. 111681, 2024, doi: 10.1016/j.buildenv.2024.111681.
16. H. R. Khan, W. Ahmed, W. Masud, U. Alam, K. Arshad, K. Assaleh, and S. A. Qazi, “Design and experimental results of an AIoT-enabled, energy-efficient ceiling fan system,” *Sustainability*, vol. 16, no. 12, Art. no. 5047, 2024, doi: 10.3390/su16125047.
17. T.-W. Tsang, K.-W. Mui, L.-T. Wong, A. C.-Y. Chan, and R. C.-W. Chan, “Real-time indoor environmental quality monitoring using an IoT-based wireless sensing network,” *Sensors*, vol. 24, no. 21, Art. no. 6850, 2024, doi: 10.3390/s24216850.
18. Texas Instruments, “NA555, NE555, SA555, SE555 precision timers,” Data Sheet SLFS022K, rev. K, Mar. 2026.
19. Texas Instruments, “CD4017B, CD4022B types,” Data Sheet SCHS027C, rev. C, Sep. 2004.
20. Vishay Intertechnology, “TSOP382.., TSOP384.. IR receiver modules for remote control systems,” data sheet, accessed Jul. 2026.
21. onsemi, “MOC3021M, MOC3022M, MOC3023M random-phase optoisolators TRIAC driver output,” data sheet, accessed Jul. 2026.
22. STMicroelectronics, “BTA12 and BTB12 standard and snubberless TRIACs,” data sheet, accessed Jul. 2026.
23. Household and Similar Electrical Appliances - Safety - Part 2-80: Particular Requirements for Fans, IEC 60335-2-80:2024, International Electrotechnical Commission, Geneva, Switzerland, 2024.
24. Automatic Electrical Controls - Part 1: General Requirements, IEC 60730-1:2022, International Electrotechnical Commission, Geneva, Switzerland, 2022.
25. Household and Similar Electrical Appliances - Safety - Part 1: General Requirements, IEC 60335-

1:2020+AMD1:2025, International Electrotechnical Commission, Geneva, Switzerland, 2025.

26. P. Horowitz and W. Hill, The Art of Electronics, 3rd ed. Cambridge, U.K.: Cambridge University Press, 2015.
27. A. S. Sedra, K. C. Smith, T. C. Carusone, and V. Gaudet, Microelectronic Circuits, 8th ed. New York, NY, USA: Oxford University Press, 2020.
28. R. W. Erickson and D. Maksimović, Fundamentals of Power Electronics, 3rd ed. Cham, Switzerland: Springer, 2020.

**Manuscript note:** *Calculated plots are analytical design checks. The reported 10 m range and approximately 1 s response originate from the supplied prototype record.*