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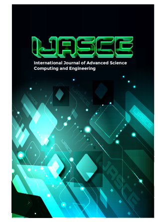

Design and Development of a Smoke-Activated Power Disconnect Device for Residential Fire Safety

Joecyn N. Archival [a,*]

[a] *Electrical Engineering Department, Cebu Technological University, Cebu City, Philippines*

*Corresponding author: *joecyn.archival@ctu.edu.ph*

***Abstract*—Fire safety remains a critical concern, particularly in managing electrical flow during fire incidents. Despite advances in detection technologies, most existing systems still cannot autonomously disrupt electrical circuits during the early stages of a fire. This study addresses that gap by proposing a novel device engineered to immediately sever electrical power upon detecting smoke from smoldering combustion in the surrounding environment. The core objective is not only to prevent fire escalation but also to reimagine and reinforce electrical safety in residential buildings. To achieve this, researchers carefully selected and integrated high-reliability electrical and electronic components, emphasizing operational efficiency and responsiveness. The experimental phase focused on evaluating key performance indicators—most notably, the latching mechanism's response efficiency. Sensitivity to smoke from a range of combustible materials was assessed by placing the materials 8 and 10 feet from the sensor. Time-response measurements quantified detection sensitivity, revealing performance variability influenced by environmental conditions and smoke density. The resulting smoke detector with an integrated latching mechanism emerges as a pivotal innovation—capable of automatically disconnecting residential electrical systems in real time. This advancement instills greater confidence in both firefighting professionals and occupants, enabling safer, more proactive fire suppression strategies, particularly those involving water. Beyond its immediate safety applications, the system offers seamless integration potential, setting a new benchmark for residential electrical infrastructure. Overall, this research advances the field of fire safety and contributes meaningfully to modernizing residential protection systems.**

***Keywords*—Fire safety; electrical systems automation; smoke detection; circuit interruption; residential infrastructure safety.**

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I. Introduction

Fire remains an unpredictable yet devastating phenomenon that, when it occurs in residential buildings, often leads to severe consequences including the loss of property, displacement of families, and tragic loss of life. Residential fire incidents remain a global concern, with statistics varying annually and reported by multiple international and national agencies. According to the CTIF World Fire Statistics Report, the United States alone recorded 374,300 residential building fires in 2022, resulting in 2,720 deaths and 10,250 injuries [1].

In the Asia-Pacific region, the Philippines witnessed a significant surge in residential fire incidents in 2023. Data from the Bureau of Fire Protection (BFP) revealed 15,900 fire incidents nationwide, a 21.1% increase from the previous year [2]. The National Capital Region reported the highest concentration of these incidents, with residential zones being disproportionately affected. Investigations identified electrical faults as the leading cause of these fires.

In contrast, countries like Japan have implemented proactive fire safety policies. Since 2006, all residential homes in Japan have been required to install residential fire alarms. A 2011 survey by the Tokyo Fire Department showed that the installation rate of residential alarms within its jurisdiction had reached 80.6% [3]. Further analysis indicated that these alarms were effective in alerting individuals not only in the room of fire origin but also in adjacent spaces, facilitating timely evacuations and potentially saving lives [4].

The growing frequency and severity of residential fires, particularly those caused by electrical malfunctions, underscore the urgent need for more advanced fire detection and prevention technologies [5], [6], [7]. Traditional fire alarm systems primarily serve as alert mechanisms but often cannot directly intervene in the electrical system, where many fires originate [8], [9]. This has spurred a new wave of innovation in integrated fire detection and energy management systems. These emerging technologies are designed to continuously monitor electrical flow and autonomously interrupt power supply upon detecting early signs of combustion, such as smoke from smoldering materials [6], [10], [11]. By addressing the root cause, unregulated electrical faults, these solutions offer a proactive approach to fire mitigation, enhancing both prevention and emergency response in residential environments.

II. MATERIALS AND METHOD

The primary objective of this study is to design and implement a reliable system that automatically disconnects electrical power in residential buildings during fire incidents by integrating a smoke detector with a latching mechanism. This system is part of a home fire detection safety system [12], [13]. The system's functionality is structured into clearly defined operational stages. This section provides an overview of the entire system and explains the roles and interactions of the various components used in the study.

A. System Design

Figure 1 illustrates the system's functional concept. The smoke detector serves as the central sensing unit, continuously monitoring the environment for smoke particles. Once smoke is detected, it promptly signals the latching mechanism. Acting as the control unit, the latching mechanism responds by automatically interrupting the flow of electricity, thereby disconnecting the residential electrical system to prevent further hazards. This integrated approach ensures a swift and reliable response during fire incidents.

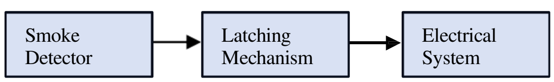

Fig. 1 Conceptual Design of the Smoke Detector Device

Figure 2 presents the system's operational flow during the working stage, the critical phase in which smoke from smoldering combustion has already been detected. Once the photoelectric smoke detector senses smoke particles in the environment, it immediately validates the presence of fire and transmits a signal (YES) to the latching mechanism. Upon receiving this signal, the latching mechanism activates and disconnects the residential electrical system, effectively cutting off the power supply to mitigate potential fire-related hazards.

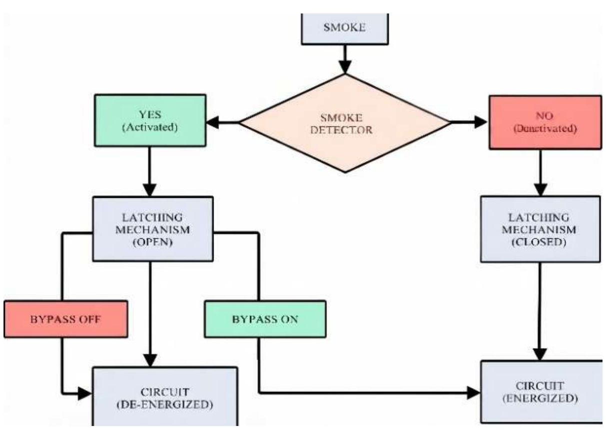

Fig. 2 System Design of a Smoke Detector with Integrated Latching Mechanism

At this point, the latching mechanism ensures that the entire electrical flow is safely interrupted, fully de-energizing the building to prevent further escalation. This system goes beyond passive detection by actively enhancing electrical safety during fire emergencies. Designed with reliability and user convenience in mind, it includes a push-button reset function, enabling safe and straightforward power restoration once the fire situation has been resolved. This feature supports efficient recovery and helps maintain operational continuity in residential settings.

B. Schematic and Components Integration of the System

The schematic diagram shown in Figure 3 illustrates the component integration within a simplified yet effective circuit. At the core of the triggering mechanism is a pushbutton with two switch types: normally closed (NC) and normally open (NO). The NC switch is directly connected to the power source (Line 1 or L1), and its terminal is linked to the NO switch. An auxiliary contact of the contactor is also connected to the NO switch, which in turn is wired to one terminal of the holding coil (H.C.) or magnetic coil of the contactor. The other terminal of the magnetic coil connects to a normally closed auxiliary relay, which is then connected to Line 2 (L2), completing the circuit.

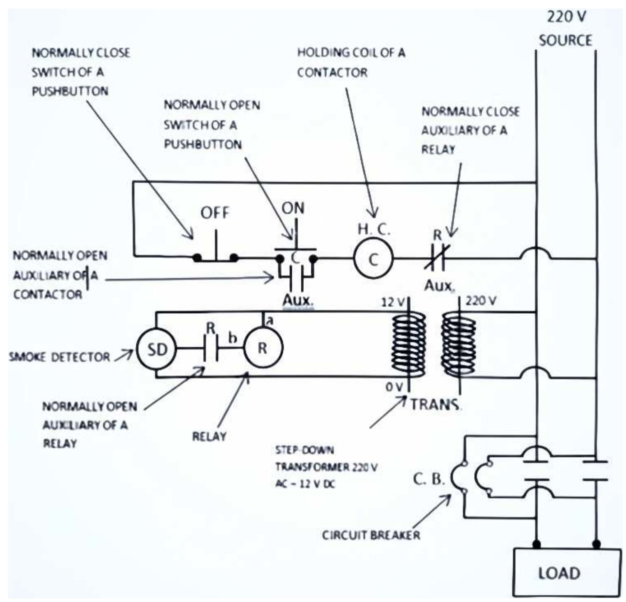

Fig. 3 Schematic Diagram of the Smoke Detector with Latching Mechanism System

A step-down transformer supplies power to the smoke detector, which functions as the system's brain and must remain energized 24/7 to ensure constant monitoring. One terminal of the relay (a) connects to the transformer's 12V output, while terminal (b) connects to one end of the smoke detector. When smoke is detected, the smoke detector sends a return signal to the relay, triggering it to open the contactor and disconnect power to the residential building's electrical system. Additionally, a circuit breaker, acting as a bypass switch, is integrated into the system. It is directly connected to both Line 1 (L1) and Line 2 (L2), providing a critical safety feature that allows for manual control and system protection during maintenance or emergency overrides.

Fig. 4 Components Integration of the System

Figure 4 illustrates the integration of all device components. The relay has a voltage rating of 12 volts and a current rating of 10 amperes. The SC-0 magnetic contactor is rated at 240 volts with a current capacity of 30 amperes, which matches the ratings of the circuit breaker (bypass switch) used in this device. The step-down transformer, rated at 12 volts and 1 ampere, powers the entire device to ensure proper operation.

C. Fire Behavior of Combustible Materials

Combustible materials such as paper, cartons, uprooted weeds, and wood each exhibit specific parameters that influence their combustion behavior. Paper and cartons, being cellulose-based, have low ignition temperatures and high surface-to-mass ratios, leading to quick ignition and intense burning. Their moisture content significantly affects their combustibility, with lower moisture levels enhancing flammability. Uprooted weeds, comprising organic plant matter, have varied moisture content and density, which impact their ignition and burn rate; dry weeds ignite easily and burn rapidly, while moist weeds resist ignition. Wood, a denser, more fibrous material, has a higher ignition temperature than paper and cartons but burns steadily once ignited. Wood type, moisture content, and arrangement influence combustibility; seasoned, dry wood ignites faster and burns hotter than green or moist wood. Understanding these parameters is essential for fire safety assessments and implementing effective fire prevention measures in environments containing these diverse combustible materials.

The fire behavior of various large polymer assemblies is under-researched. Understanding the heat release rate of different combustibles is essential for fire risk assessment. Two configurations were tested: juxtaposed and layered materials, using a radiant panel setup. In juxtaposed assemblies, the more flammable component accelerated combustion. In layered assemblies, the front material shielded and delayed combustion of the backside material, while the backside material induced thermal thickening, slowing down the front material's combustion. Experimental results were compared with simulated models using time offsets and slowdown factors [14].

The experimental findings on early-phase fires in office buildings used materials such as wood, linoleum, paper, and cardboard. Key fire characteristics recorded include temperature, heat release, burnout time, and flue gas concentration. The study analyzed fire detector activation stages and found flame and smoke detectors most effective. Combining detectors enhances fire detection and recording. The study provided recommendations for optimizing fire detection systems, emphasizing the importance of using the findings to improve fire safety in office settings [15].

III. RESULTS AND DISCUSSION

This section examined the presentation, analysis, and interpretation of the gathered data. The analytical procedures were arranged according to the sequence of tests or evaluations of parameters that ensure the device's reliability and overall functionality.

A. Efficiency of the Device

The device's response depends on the smoke detector (photoelectric) sensitivity. Thus, the smoke detector's sensitivity in experimental testing was measured by the amount of smoke produced by the specific combustible materials used and the response time at two vertical distances from the device: 8 feet and 10 feet.

B. Experimental Set-Up

The experimental tests for the device's efficiency considered two vertical distances: 8 feet and 10 feet. During random testing of the smoke detector's sensitivity, it was observed that its response in sending a signal to the latching mechanism depended on the amount of smoke particles present in the surroundings.

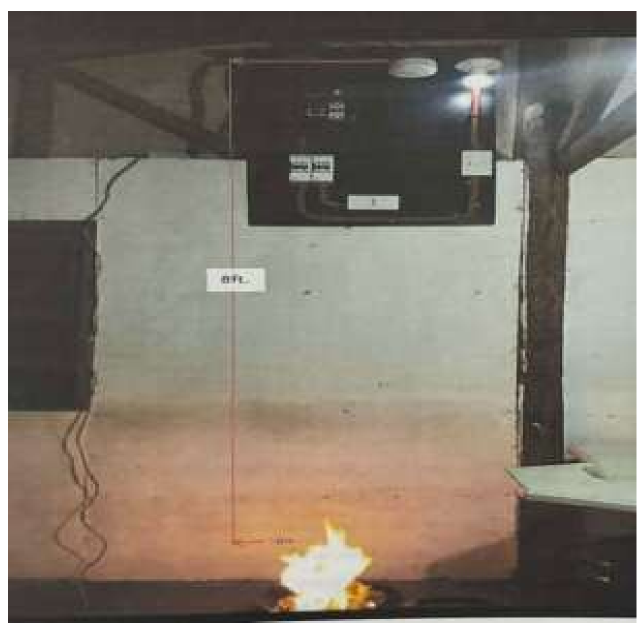

Fig. 5 Experimental Set Up at 8 feet vertical distance

Fig. 6 Experimental Set Up at 10 feet vertical distance

Since the standard vertical distance between the floor and ceiling in residential households is 10 feet, most buildings follow this height. Consequently, an 8-foot vertical distance was also used in the experimental process. However, to strictly adhere to NEPA 72, installing the smoke detector must not compromise the set standards for proper device placement in residential buildings.

C. Results of Actual Testing of the System

The randomized testing of the smoke detector with a latching mechanism, as presented in Table 1, provides critical insights into the device's real-world functionality, particularly its smoke sensitivity and response efficiency. The experiments, which varied both the combustible materials and the vertical distance (8 and 10 feet), were designed to simulate different fire scenarios commonly encountered in residential environments.

TABLE I
RESULTS OF THE ACTUAL TESTING

Test No.	Vertical Distances (feet)	Weight (kg)	Materials	Time Response (sec)
1	8	1	Papers/Cartons	48
2	8	1	Uprooted Weeds	21
3	8	1	Woods	65
4	10	1	Papers/Cartons	53
5	10	1	Uprooted Weeds	25
6	10	1	Woods	88

The findings reveal that material type and smoke density, rather than vertical distance, were the primary factors influencing detection time. Uprooted weeds, which emit thinner smoke, were detected more quickly (21–25 seconds) than woods, which produce denser smoke and led to longer response times (65–88 seconds). Papers and cartons consistently triggered mid-range responses (48–53 seconds), suggesting moderate smoke density.

This demonstrates that the device effectively adapts its sensitivity to various combustion conditions, ensuring consistent and timely detection regardless of height variation. The system's performance shows its ability to detect smoke early, giving occupants enough time to act, whether evacuating or suppressing the fire [16], [17]. Additionally, the integrated latching mechanism that disconnects the electrical supply further enhances safety by preventing fire escalation due to electrical faults [18], [19]. These results validate the device's practical applicability in residential settings and its role in elevating fire safety standards [20], [21]. Its adaptability and rapid response emphasize the potential for broader implementation in homes, particularly where early fire detection and immediate electrical disconnection are crucial [20], [21]. Overall, the study supports integrating such innovative fire-safety technologies into modern residential infrastructure, contributing significantly to the proactive management and mitigation of fire-related risks [20], [21].

A series of full-scale fire tests were conducted to determine whether photoelectric-type smoke detectors could respond to the same types of fires used to assess the performance of ionization-type smoke detectors. The types of fires employed in the tests are the same as those outlined in Underwriters Laboratories, Inc., Standard No. 167. In addition to the UL-167 test fires, the test series included fires involving polyurethane (flaming mode) and cotton (smoldering mode). The test series included one detector using a Taguchi gas sensor (TGS) for evaluation. The test results indicated that the better photoelectric smoke detectors, those with little obstruction to slow-moving smoke, could generally detect the same test fires as the ionization chamber smoke detectors in approximately the same time scale. For the smoldering cotton fire, the photoelectric detectors were significantly faster than the ionization chamber detectors. The TGS fire detector was unable to detect most of the test fires, highlighting the ambiguity and lack of specificity in the standard test fires [22].

IV. CONCLUSION

This study successfully demonstrates the viability and effectiveness of a smoke detector integrated with a latching mechanism as a proactive fire safety solution in residential settings. By addressing a critical gap in existing systems—the inability to automatically disrupt electrical circuits during the early stages of a fire —the device represents a significant advancement in fire prevention technology. The carefully selected components, combined with rigorous experimental testing, confirm the system's responsiveness and reliability under varied environmental conditions. The device not only enhances early fire detection but also actively mitigates electrical hazards by promptly severing power, thereby reducing the risk of escalation and enabling safer use of water-based suppression methods. Its seamless integration into standard residential infrastructure underscores its practical applicability and long-term value. ultimately, this innovation marks a meaningful step forward in modernizing residential fire safety systems, promoting a more resilient and secure built environment for communities.

References

[1] Center for Fire Statistics, "World fire statistics," International Association of Fire and Rescue Services, 2023. [Online]. Available: https://ctif.org/.

[2] B. Cariaso, "BFP records 21.1 percent increase in fires in 2023," *The Philippine Star*, 2024. [Online]. Available: https://www.philstar.com/nation/2024/01/01/2322698/bfp-records-211-percent-increase-fires-2023.

[3] Y. Minegishi, W. Takahashi, and Y. Ikehata, "Experimental study of occupants' situational awareness during a fire by sounding of wireless, interconnected alarm smoke detectors at a small-scale hostel that was originally a single-family house," *Jpn. Architectural Rev.*, vol. 7, no. 1, Jan. 2024, doi: 10.1002/2475-8876.12453.

[4] A. Sekizawa and M. Mizuno, "Analysis of response behavior of people in fire incidents where residential fire alarms successfully worked," *Fire Mater.*, vol. 41, no. 5, pp. 441–453, Jun. 2017, doi:10.1002/fam.2434.

[5] M. Ma, C. Xu, and J. Han, "Application of an intelligent electrical fire monitoring system based on the EC-IOT framework in high-rise residential buildings," *Syst. Soft Comput.*, vol. 7, p. 200257, Dec. 2025, doi: 10.1016/j.sasc.2025.200257.

[6] A. Antunovic, M. Arlovic, J. Balen, and L. Seric, "Advances in fire detection and suppression: A review of contemporary methods and technologies," *IEEE Access*, vol. 13, pp. 205110–205133, 2025, doi:10.1109/access.2025.3638631.

[7] H.-D. Thai, N.-B.-V. Le, D. Lee, and J.-H. Huh, "A survey of electrical fire causes assessment technology," *IEEE Access*, vol. 12, pp. 145378–145392, 2024, doi: 10.1109/access.2024.3437175.

[8] X. Ma *et al.*, "Fire warning sensing materials: Advances, prospects, and challenges," *Emerg. Manage. Sci. Technol.*, vol. 5, no. 1, 2025, doi: 10.48130/emst-0025-0003.

[9] J. Paś, T. Klimczak, A. Rosiński, and M. Stawowy, "The analysis of the operational process of a complex fire alarm system used in transport facilities," *Build. Simul.*, vol. 15, no. 4, pp. 615–629, May 2021, doi: 10.1007/s12273-021-0790-y.

[10] T. Kairouz and H. A. Hashim, "Toward autonomous wildfire management: Advances in multimodal sensing, AI detection, sensor fusion, estimation and decision support review," *Results Eng.*, vol. 32, p. 112218, Dec. 2026, doi: 10.1016/j.rineng.2026.112218.

[11] F. Khan *et al.*, "Recent advances in sensors for fire detection," *Sensors*, vol. 22, no. 9, p. 3310, Apr. 2022, doi:10.3390/s22093310.

[12] A. J. Y, R. S, R. F. F, and P. Rithik, "Home safety system with earthquake and fire detection," in *Proc. 3rd Int. Conf. Advancements Elect., Electron., Commun., Comput. Autom. (ICAECA)*, Apr. 2025, pp. 1–6, doi: 10.1109/icaeca63854.2025.11012158.

[13] J. Yépez and S.-B. Ko, "IoT-based intelligent residential kitchen fire prevention system," *J. Electr. Eng. Technol.*, vol. 15, no. 6, pp. 2823–2832, Aug. 2020, doi: 10.1007/s42835-020-00529-z.

[14] C. Vincent, L. Ferry, C. Longuet, L. Aprin, and G. Rambaud, "Method to characterize the fire behavior of materials assemblies," *Fire Mater.*, vol. 42, no. 6, pp. 627–637, Mar. 2018, doi: 10.1002/fam.2516.

[15] A. Zhdanova, R. Volkov, A. Sviridenko, G. Kuznetsov, and P. Strizhak, "Influence of compartment fire behavior at ignition and combustion development stages on the operation of fire detectors," *Fire*, vol. 5, no. 3, p. 84, Jun. 2022, doi:10.3390/fire5030084.

[16] Y. Choi, S. Yang, and S. Kim, "The smoke control system to improve the possibility of evacuation from fire disasters in high-rise buildings," *Therm. Sci. Eng. Prog.*, vol. 59, p. 103269, Mar. 2025, doi:10.1016/j.tsep.2025.103269.

[17] C.-J. Hsiao and S.-H. Hsieh, "Real-time fire protection system architecture for building safety," *J. Build. Eng.*, vol. 67, p. 105913, May 2023, doi: 10.1016/j.jobe.2023.105913.

[18] T. H. Gillman and I. Le May, "Mechanical and electrical failures leading to major fires," *Eng. Failure Anal.*, vol. 14, no. 6, pp. 995–1018, Sep. 2007, doi: 10.1016/j.engfailanal.2006.11.049.

[19] R. A. Yereance and T. Kerkhoff, *Electrical Fire Analysis*. Springfield, IL, USA: Charles C Thomas Publisher, 2010.

[20] L. White and R. Ajax, *Improved Fire Detection and Alarm Systems*, 2025.

[21] V. Kodur, P. Kumar, and M. M. Rafi, "Fire hazard in buildings: Review, assessment and strategies for improving fire safety," *PSU Res. Rev.*, vol. 4, no. 1, pp. 1–23, Sep. 2019, doi: 10.1108/prr-12-2018-0033.

[22] R. W. Bukowski and R. G. Bright, *Results of Full-Scale Fire Tests With Photoelectric Smoke Detectors*. Gaithersburg, MD, USA: National Bureau of Standards, 1975, doi: 10.6028/nbs.ir.75-700.