Original Article

Development and Functional Evaluation of an Enclosed Shoe Drying and UV-C Disinfection System for Footwear Hygiene

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Abstract

Footwear maintenance is a universal struggle during rainy seasons because wet shoes dry slowly indoors, leading to foul odor and promoting bacterial growth. To solve this common problem, this study developed ShoeGuard, an automated shoe-drying and disinfection appliance. The development followed the systematic Product Development Process, which guides the project through planning, concept development, system-level design, detail design, testing and refinement, and implementation. Technical observations were conducted using specific performance indicators and functional qualities related to moisture extraction and automation. In terms of technical performance, the blower velocity and UV-C radiation intensity both reached optimal levels, while the digital timing display and power consumption were highly accurate and energy-efficient, respectively. In terms of functional quality, the prototype passed the total moisture extraction test. The automation control also passed all functional trials. 30 respondents evaluated the prototype. Under functional quality, the blower effectively dried deep fabric (M=4.68, strongly agree). For operational convenience, the average weighted mean was also excellent (AWM = 4.37, strongly agree). In conclusion, the ShoeGuard is a functional product that successfully combines rapid drying and disinfection. It is recommended that future researchers incorporate smart sensors that adjust drying time based on shoe wetness and

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apply different light placements inside the machine to ensure the UV-C rays reach the deep interiors of the shoes effectively.

Keywords: Disinfection device, footwear maintenance, performance indicators, product development, satisfaction levels

1. Introduction

Nowadays, many households prefer to use automated appliances to save time and effort. However, cleaning and maintaining shoes is still a major problem for many families, especially during the rainy season. When heavy rain suddenly falls, shoes get completely soaked. It is very hard to dry them outside because the weather is unpredictable. When drying shoes inside the house, they do not dry completely. They stay damp, create a bad smell, and become a perfect breeding ground for bacteria and fungi.

Modern household appliances use heat and moving air to speed up the drying process in order to address this issue. Engineering studies show that tracking airflow inside a drying machine improves moisture removal much better (Guangbin et al., 2022). Using built-in heating elements and dehumidifiers also keeps the drying temperature steady, even if the weather outside changes (Su et al., 2024). Additionally, studying how water is squeezed out helps engineers design better drying chambers for home use (Serrato et al., 2025). Aside from drying, killing bacteria inside damp shoes is very important to keep them clean and safe. Many new technologies now use ultraviolet (UV-C) light to disinfect surfaces and kill germs quickly (Bowers et al., 2025). When building these sanitizing devices, engineers must focus on the users. This ensures that the automatic disinfection works well and does not cause electric shocks or dangerous radiation to the family (Belay et al., 2025). Designing a closed lighting box is also necessary to maintain UV light strong enough to kill tough germs safely (Mohsin et al., 2024). As a result, the use of portable UV-C modules has become a basic requirement for modern home appliances (Ng & Mont, 2025).

To ensure the drying and sanitizing functions work together smoothly, home appliances need simple automation. Smart systems in devices help monitor processes in real time and prevent electrical overloads (Adriani et al., 2022). Home devices also require fast-acting relays to protect the internal parts from sudden power spikes (Ghiasi et al., 2024). As stated by Thangaraj et al. (2026), some technological setups incorporate automatic rain covers in addition to programmable timers, creating a self-regulating system that functions well without human intervention. Lastly, a simple screen layout and easy buttons allow users to set up the appliance without any confusion (Chen & Lu, 2025). The most important part of making a new appliance is balancing high technology with user convenience. Machines should not be complicated to use. For example, providing users with quick tips on how to save energy can lower electricity bills and make the machine more useful (Eirinaki et al., 2022). For devices that dry and disinfect, shaping the machine's layout based on what the user actually needs ensures they are used over the long term (Bezerra & Silva, 2023). We can see this in specialized healthcare equipment, where built-in drying and cleaning loops directly improve user comfort (Mane et al., 2025). Using simple, automated screens instead of manual tracking also reduces mistakes and makes the machine easier to operate (Mencias et al., 2024). Therefore, closely examining how the hardware is built is very important because a simple design builds consumer trust and confidence (Lucila, 2026).

Although several commercial footwear dryers with built-in UV-C functionality are on the market, most consumer units rely on low-velocity ambient air circulation or passive conduction. Existing configurations frequently struggle to properly dry dense internal fabric and foam layers in a short period of time. In addition, conventional devices lack optimized chamber designs to facilitate forced-air circulation and controlled UV-C exposure, making it difficult to dry dense internal fabric. This gap has prompted the development of the ShoeGuard prototype, which focuses on fluid dynamics and mechanical safety. The device uses high-velocity forced convection in a compact, enclosed chamber to safely, quickly, and uniformly break up stagnant internal moisture boundary layers. It also uses automated cycle controls and thermal precautions.

To address this gap, this study developed and evaluated the ShoeGuard prototype guided by the generic Product Development Process framework. This systematic approach structured the hardware engineering and safety optimization across six distinct phases: planning, concept development, system-level design, detail design, testing and refinement, and implementation. Specifically, this study aims to evaluate the technical system performance levels of the developed ShoeGuard and the functional quality in terms of moisture extraction and automation control. Also, the respondents' satisfaction with the ShoeGuard's functional performance and operational convenience was evaluated to assess how well the system serves as an efficient solution for footwear maintenance.

2. Methodology

2.1 Design

This study used a descriptive-developmental research design to create, test, and evaluate the ShoeGuard prototype. The engineering and hardware development phase was patterned after the generic Product Development Process framework by Ulrich et al. (2008). This systematic method guided the project from a simple problem to a fully functioning household appliance.

Furthermore, household users' perceptions of the device's real performance were collected and analyzed during the descriptive phase. Through a structured evaluation survey, respondents gave their perceptions by rating the prototype based on performance indicators, including system performance, functional effectiveness, and operational convenience. Combining these two methods enabled the study not only to develop a functional product but also to verify its practical convenience and effectiveness in addressing real-world footwear hygiene problems during continuous rainy days.

2.2 Product Development of ShoeGuard

The development of the ShoeGuard prototype was carried out in accordance with the structured generic Product Development Process developed by Ulrich et al. (2028), which was executed across six sequential phases: Planning, Concept Development, System-Level Design, Detail Design, Testing and Refinement, and Implementation.

Planning: The research team identified the problem of thoroughly drying and sanitizing washed footwear indoors during the continuous rainy season. The core target requirements identified a shoe-drying machine capable of rapid moisture extraction and odor elimination without damaging shoe textiles.

Concept Development: During this process, architectural strategies were developed to remove moisture and provide germicidal action simultaneously. The product concept was finalized as an enclosed box-type cabinet that uses a dual-action cycle combining warm convective airflow and germicidal UV-C light sanitation in a single compact unit.

System-Level Design: The device's interior layout and functional layout were designed as a box-type configuration. The appliance's overall dimensions were compact, measuring 50 × 35 × 50.7 cm to optimize space efficiency in domestic entryways (Figure 1). A dual-action electrical system powered by a 12V DC, 120W power source was specified in the device's physical plan. The overall control logic integrated a Digital Cycle Timing Delay Relay with an LED Display, a manual speed-controller knob, a 13,000-RPM internal blower system for warm convective air transfer, and an embedded UV-C sanitation module.

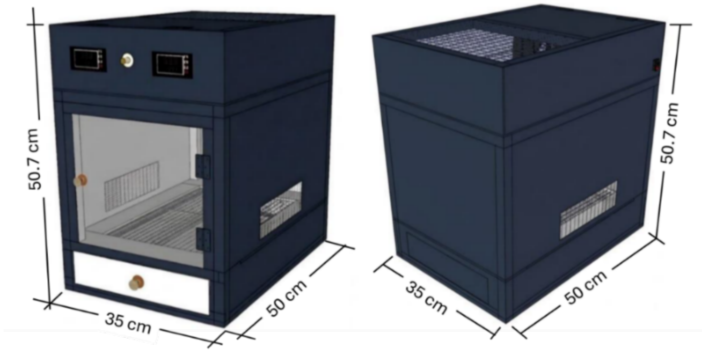

Figure 1. Product design of ShoeGuard.

Detail Design: Individual hardware components were selected, manufactured, and fully integrated into the design (Figure 2). The internal drive mechanism relies on a heavy-duty DC Power Supply, interfaced with an AC Power Socket, to ensure secure power distribution throughout the enclosure. Airflow and thermal regulation are controlled by a dual-system layout containing a DC Portable Blower and an integrated Motor Speed Controller. A UV Digital Timing LED Display and a Dryer Digital Timing LED Display handle Independent tracking of active cycles. The physical housing is constructed with a solid chassis, a transparent acrylic door, and a stainless-steel magnetic latch, enabling safe visual inspection during operation. Footwear rests on a steel wire mesh that allows extracted moisture to drip into a removable, sliding Drain Compartment at the base, ensuring compliance with domestic safety standards.

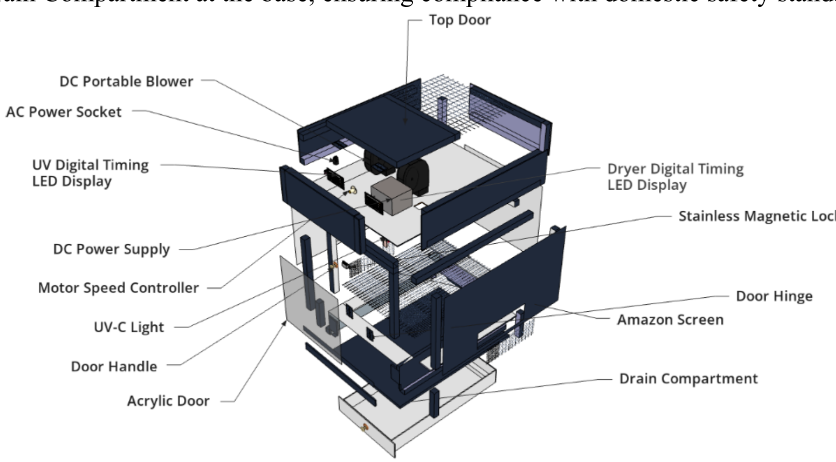

Figure 2. Exploded diagram of ShoeGuard.

Testing and Refinement: The research team conducted controlled laboratory experiments to evaluate both functional quality criteria and technical performance indicators. During this phase, the primary purpose was to measure ShoeGuard's performance indicators and functional quality parameters. During these controlled laboratory tests, minor hardware calibrations and control timing adjustments were made in preparation for the full-scale deployment of the system.

In addition, the Microbiological Testing Laboratory of the Department of Science and Technology, as well as the Philippine Textile Research Institute (DOST-PTRI; Test Report No. 028M-26), conducted standardized laboratory testing to evaluate antibacterial efficacy. Circular fabric swatches measuring 3.8 cm in diameter (Sample Code: MIC-0036 / LLC-1) were prepared to simulate internal footwear linings, with Staphylococcus aureus utilized as the test organism. Specimens were inoculated with 0.2 mL of culture suspension containing an initial load of 1- 3 × 10 ^5 CFU/mL (2.1 x10^5 CFU/Carrier} for control in Tryptic Soy Broth (TSB) and exposed to germicidal UV-C light inside the chamber for 30 minutes. Untreated inoculated control swatches were maintained under identical conditions as a baseline. Bacterial extraction was performed using 20 mL of Dey-Engley Neutralizing Broth via vortex mixing (5 seconds across 5 cycles), and viable colonies were enumerated on Tryptic Soy Agar (TSA) following incubation at 37 ± 2 °C for 24–48 hours. The percent bacterial reduction was determined by comparing the number of viable test organisms recovered from the 30-minute UV-C exposure cycle against the initial bacterial load recovered from untreated control test carriers.

Implementation: The final ShoeGuard prototype in real household settings. To see how well the device works, the prototype was deployed to thirty (30) selected household end-users from Quezon City District VI. Participants tested the device under actual operating conditions using washed canvas sneakers. Feedback on satisfaction was collected to measure respondents' perceptions of ShoeGuard's functional effectiveness and operational convenience (Figure 3).

Figure 3. Actual prototype.

2.3 Participants

The participants of this study consisted of thirty (30) household end-users residing within District VI of Quezon City. To select participants responsible for daily chores and footwear care who experience difficulties drying wet shoes and dealing with odor during heavy rainy seasons, purposive sampling was used. Each participant had the opportunity to try and evaluate the ShoeGuard prototype in a normal home environment. By collecting feedback, the study obtained perceptions on the product's functional effectiveness and operational convenience.

2.4 Locale of the Study

The study was strategically conducted within District VI of Quezon City, Philippines. This specific environment provided the ideal real-world testing conditions for the ShoeGuard prototype, as local households constantly struggle with the everyday domestic problems of drying thick footwear and preventing the sour odor of their shoes. San Bartolome Main Campus of Quezon City University (QCU) served as the anchor for the technical design, production, and laboratory calibration. A smooth transition from controlled laboratory engineering to actual field-testing deployment was made possible by connecting QCU's academic facilities directly to the surrounding homes of District VI.

2.5 Instruments

The primary tool used to collect data for this study is a researcher-developed survey questionnaire, verified by a panel of engineering education experts to guarantee structural clarity. The instrument was divided into two parts to capture users' perceptions regarding functional effectiveness and operational convenience. The respondents' perceptions were measured using a Likert scale. The first part focused on establishing the respondents' profiles and understanding their current footwear maintenance habits. This part began with respondent classification, footwear-drying methods, and challenges experienced during the rainy season.

The second part of the instrument focused on measuring respondents' overall satisfaction with the device. This assessment used a five-point Likert Scale to quantify the data. First, it assessed the product's functional effectiveness in sanitizing footwear, measuring how well the combination of active airflow and UV-C radiation removes moisture and reduces bacterial or mold growth. Second, it assessed operational convenience, focusing on the device's user-friendliness, the clarity of the digital timing display, and how easily an ordinary household consumer can manage the appliance layout.

2.6 Data Collection

The data-gathering procedure used a two-phase design to separate technical hardware testing from consumer satisfaction. In the first phase, the researchers directly recorded the prototype's core performance and functional quality through controlled laboratory trials. In the second phase, the prototype was deployed for usability testing among a purposive sample of thirty (30) household end-users in Quezon City District VI. After interacting with the device, the respondents' perceptions were gathered regarding their level of satisfaction with using the ShoeGuard in terms of Functional Effectiveness and Operational Convenience. All collected data were compiled and statistically analyzed. The data-gathering procedure used a two-phase design to separate the technical hardware testing from consumer satisfaction level. In the first phase, the researchers directly recorded the prototype's core performance and functional quality through controlled laboratory trials.

In the second phase, the prototype was deployed for usability testing among a purposive sample of thirty (30) household end-users in Quezon City District VI. After interacting with the device—including adjusting the speed knob, loading shoes through the acrylic door, and emptying the drain tray—the respondents evaluated it using a 5-point Likert scale survey questionnaire. The instrument was divided into two parts: Part A (Functional Effectiveness), which assessed drying and odor-stopping performance, and Part B (Operational Convenience), which evaluated the ease of setting the timing relay controls and maintaining the unit. All collected data were compiled and statistically analyzed.

2.7 Limitations of the Study

This study is limited to five (5) trials under laboratory conditions to monitor the technical system performance of the prototype. In addition, the testing is limited solely to canvas footwear. The findings do not apply to alternative footwear materials, including leather, rubber, or synthetics.

2.8 Ethical Considerations

This study strictly adhered to all ethical research guidelines, including those pertaining to device operation and the safety of human subjects. Informed consent was obtained from respondents. All participants had the right to withdraw at any time without penalty, as participation was completely voluntary. To preserve participants' privacy, no personal identifiers were recorded, ensuring data confidentiality. Also, the prototype was designed with a fully enclosed illumination chamber to ensure that heat stays out of direct contact while in use.

2.9 Data Analysis

Descriptive statistics were utilized to evaluate the collected quantitative data. The arithmetic mean was calculated for each performance indicator using the data obtained from respondents' perceptions. Furthermore, the weighted mean was computed to determine the comprehensive household satisfaction level for both Functional Effectiveness and Operational Convenience.

3. Results

3.1 Technical System Performance of ShoeGuard

To examine the technical system performance levels of the ShoeGuard prototype, performance indicators were used. The standard target ratings in Table 1 were determined in accordance with international engineering and sanitary standards to ensure safe and effective operation: the blower velocity target (4.0 m/s) was based on forced-convective airflow guidelines for enclosed drying chambers to ensure adequate boundary-layer moisture transfer without imposing thermal or mechanical stress on shoe fabrics. To disinfect microorganisms on surfaces within short time frames, the target intensity for germicidal UV-C was determined to be 250 µW/cm², which was based on the known microbial inactivation dosages that are required; the display accuracy limit (1.0 s) was selected to maintain accurate timing relay control; and the power consumption limit (60 W) was specified to maintain domestic energy efficiency. The operational performance was monitored over five (5) continuous independent trials under controlled laboratory conditions, as detailed in Table 1.

Table 1. Technical system performance levels of ShoeGuard.

Performance Indicator	Trial					Mean	Target Rating	Remarks
	1	2	3	4	5			
1. Blower Velocity *(m/s)*	4.2	4.1	4.3	4.2	4.2	**4.2**	≥ 4.0 m/s	Optimal
2. UV-C Radiation Intensity *(uW/cm²)*	252	250	255	251	252	252	≥ 250 µW/cm²	Optimal
3. Digital Timing LCD Display Accuracy *(Seconds)*	0.2	0.2	0.1	0.3	0.3	0.22	≤ 1.0 s	Highly Accurate
4. System Power Consumption *(Watts)*	45.2	45	45.5	45.1	45.2	45.2	≤ 60.0 W	Energy Efficient

The blower velocity was consistently maintained at an optimal rate across all experimental trials (M=4.2 m/s), meeting the standards for convective heat distribution. It was observed that the intensity of germicidal UV-C radiation consistently surpassed the parameters for pathogen reduction, which is required for surface sanitization (M=252 µW/cm², optimum). Additionally, the digital timing LCD demonstrated precise timing control (M=0.22 s, Highly Accurate), while overall system power consumption remained low and energy-efficient throughout continuous operation (M=45.2 W, energy efficient).

The results confirm that the hardware architecture has an excellent operational balance between synergistic airflow and low power consumption, demonstrating that high-velocity moisture evaporation is possible without straining domestic power supplies. Simultaneously, Digital timing relay precision ensures the UV-C module operates within safe, calibrated exposure cycles. This 5-trial testing framework proves technical capability and short-term processing stability.

3.2 Assessment of the Functional Quality

The functional quality of ShoeGuard was evaluated in five (5) trials lasting 60-90 minutes. The initial tests demonstrated that the prototype functions properly and is suitable for short-term use. The target operational standards established in Table 2 were derived directly from the total moisture extraction rate target (3.00 ml/min), which was set to ensure saturated footwear dries within 60 to 90 minutes under high humidity, while the automation interface delay limit (1.00 s) guarantees real-time system responsiveness and user safety

As shown in Table 2, the total moisture extraction rate comfortably exceeded the minimum operational target for heavy canvas shoes (M=3.34 ml/min; Passed). A similar pattern was observed with the automation control and interface delay, which displayed minimum system latency (M=+0.22 s, Passed). The minimal automation delay ensured by these functional performance results in control switching, which directly supports the sustained heating and forced ventilation required for uniform moisture extraction.

Table 2. Assessment of the functional quality of the developed ShoeGuard.

Functional Quality	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Mean**	**Target Rating**	**Remarks**
	(60 mins)	(60 mins)	(75 mins)	(90 mins)	(90 mins)			
Total Moisture Extraction Quality (ml/min per pair)	3.4	3.2	3.5	3.3	3.3	3.34 ml/min	≥ 3.00 ml/min	*Passed*
Automation Control & Interface (sec delay)	0.2	0.2	0.1	0.3	0.3	+0.22 sec	≤ 1.00 sec	*Passed*

3.3 Respondents' Satisfaction Level in Terms of Functional Effectiveness

The respondents' perception of ShoeGuard's functional effectiveness received highly positive user feedback (AWM=4.31, Strongly Agree), as shown in Table 3. These high ratings indicate that the prototype's automatic drying and sanitation mechanisms meet users' expectations for a shoe-drying device. In user experience, a sample of 30 participants is a well-established benchmark for prototype testing to identify core interface flaws, usability issues, and safety issues. Basic washed canvas shoes were used to establish a baseline for high moisture-retention functional effectiveness, which cannot be applied to all footwear types, as genuine leather, vulcanized rubber, and mesh exhibit different heat distribution, thermal sensitivity, and moisture desorption rates.

Table 3. Respondents' satisfaction level in terms of functional effectiveness.

Functional Effectiveness	Mean	Remarks
1. The blower system effectively dries the deep fabric and foam layers of washed shoes within 1 to 1.5 hours.	4.68	Strongly Agree
2. The UV-C Light sanitizer eliminates odor-causing microorganisms in wet footwear.	4.15	Agree
3. The device serves as a reliable shoe care alternative when sun-drying is impossible.	4.18	Agree
4. The system improves foot hygiene by keeping footwear dry, fresh, and sanitized.	4.23	Strongly Agree
AWM	4.31	Strongly Agree

These high satisfaction ratings reflect users' direct experience with the unit's drying and sanitizing functions. To complement these subjective user evaluations, objective laboratory testing of the prototype's antibacterial performance was conducted by a third-party laboratory to empirically validate its germicidal efficacy.

3.4 Respondents' Satisfaction Level in Terms of Operational Convenience

The prototype's operational convenience was evaluated to assess its comfort during daily operations. As shown in Table 4. The overall rating reflects a high satisfaction level (AWM=4.37, Strongly Agree). This demonstrates that improvements in user engagement can be achieved through ergonomic hardware, such as the mess-free drainage tray and the haptic speed controller, as well as clear visual cues, such as the countdown LED display. The design minimizes operational complexity, and the maintenance workload meets functional usability standards for sanitizing footwear used in regular home activities.

Table 4. Respondents' satisfaction level in terms of operational convenience.

Operational Convenience	Mean	Remarks
1. Setting the operating time using the digital delay relay module is simple and user-friendly.	4.33	Agree
2. The digits on the countdown LED display are clear and highly visible even from a distance.	4.45	Strongly Agree
3. Adjusting the speed controller knob is smooth and gives full control over the airflow intensity.	4.20	Agree
4. Sliding out the removable lower drain compartment to empty the collected water is convenient and mess-free.	4.48	Strongly Agree
AWM	4.37	Strongly Agree

4. Discussion

To establish the basis for the technical system performance of the ShoeGuard prototype, first, the blower velocity target of 4.0 m/s was set because this airspeed provides optimal forced airflow required to penetrate dense footwear interiors and accelerate moisture evaporation without causing structural or thermal damage to delicate shoe fabrics (Luan et al., 2026). Second, the UV-C radiation intensity threshold of 250 $\mu W/cm^2$ was set because this irradiance level effectively inactivates persistent odor-causing bacteria (Nguyen et al., 2022). Third, the operational display accuracy threshold was set to ±1.0 s to account for drift in the internal oscillator and to prevent delays in switching from the display to the relay (Adriani et al., 2022). Fourth, to ensure it operates within low-power domestic energy-efficiency thresholds, a 60.0 W power consumption limit was set based on the combined power budget of the internal components (Eirinaki et al., 2022).

As shown in the data on the technical system performance levels of the ShoeGuard prototype, the speed of the air produced by the DC Portable Blower was measured with an anemometer. As tracked across the five testing cycles, the blower system consistently maintained a strong, steady airflow that met the minimum required target for drying footwear. This air speed indicates that the blowers have more than enough power to push air deep into the narrowest parts of the shoes. By ensuring the air reaches the very end of the footwear, the machine traps moisture, making the drying process both fast and reliable. The intensity of ultraviolet (UV-C) light was assessed to ensure it effectively cleans the footwear interior. The ultraviolet light module consistently produced stable light that easily met the standard baseline requirements for safe appliance sanitization. The findings indicated that a fully enclosed interior prevents the creation of dark shadow zones. The blower's stable air delivery and UV-C Irradiance closely align with the findings of Ng and Mont (2025), who showed that portable UV-C devices are highly effective at cleaning surfaces. This stable performance confirms that the physical setup of ShoeGuard delivers powerful cleaning, as the light evenly reaches all parts of the shoes while the machine is running. To ensure device safety, the prototype incorporates features that address possible overheating, thermal risks, UV-C exposure or leakage, and the safety mechanisms of the enclosed system. UV-C exposure or leakage is prevented by an enclosed opaque housing, sealed viewing panels, and an internal safety switch that automatically cuts power to the UV-C module whenever the door is opened.

Meanwhile, potential overheating and thermal risks are mitigated by continuous airflow from the blower, which cools internal components, and by a digital timer that automatically shuts down the system after each cycle. The accuracy of the built-in screen timers, specifically the UV Digital Timing LED Display and the Dryer Digital Timing LED Display, was tested by comparing their countdowns against a precise digital stopwatch. The digital screen controls show only a tiny delay of a fraction of a second (M=+0.22 sec). This data aligns with the findings of Adriani et al. (2022), who noted in their appliance research that precise timing is significant because it directly affects how safely the system handles power, helping ensure that internal components prevent electrical overloads and operate efficiently. The total electrical energy used by all parts of the machine, including the blower, UV-C module, and speed controllers, was monitored with a digital power analyzer. The prototype operated with an eco-friendly, energy-saving profile that remained well below the maximum energy design limit (Energy Efficient). This low wattage means the ShoeGuard uses roughly the same amount of electricity as a standard household light bulb, proving it can run safely without incurring the high costs reported by Eirinaki et al. (2022), who found that using low-consumption appliances is an effective way to manage residential power demand. However, a notable limitation of this evaluation is its reliance on only five technical trials, which demonstrate short-term prototype performance rather than long-term reliability. Consequently, extended stress-testing under prolonged continuous operation is recommended for future evaluation.

In terms of the functional quality of the ShoeGuard, total moisture extraction was evaluated using a digital weighing scale to measure the water reduction of a fully saturated footwear pair containing 250 grams (0.25 Liters) of absorbed laundry water. The system demonstrated stable moisture extraction across all testing durations (M = 3.34 ml/min; Passed). The heat from the motor swiftly converts the water inside the shoe's fabric and foam into vapor, while continually circulating air. The blower acts as a mechanical squeezer, forcing water droplets out of the footwear. This heat-drying concept aligns with the drying principles of Serrato et al. (2025), which show that forced-air drying quickly removes deep moisture from thick fabric. Additionally, the results of Su et al. (2024) showed that maintaining humidity inside a closed cabinet makes the system effective while shielding it from water damage. Guangbin et al. (2022), who discovered that adding a sealed chamber with continuous air circulation considerably increases the overall drying time. The automation control & interface achieved timing precision relative to a digital stopwatch (M=+0.22 sec, Passed). This control layout allows users to safely monitor the internal operational state in real-time through the clear acrylic door panel. This interface immediately cuts power to both the blower and the UV-C light modules to ensure user safety as soon as the cycle ends. This quick shut-off interface aligns with the safety models of Ghiasi et al. (2024), which state that a split-second delay in relays is crucial to prevent electrical leaks. Moreover, combining automatic drying aligns with the system designs of Mane et al. (2025), who found that synchronizing forced-air drying with timed UV-C irradiation yields energy-efficient operation.

The respondents' perception of ShoeGuard's functional effectiveness received highly positive user feedback. The system achieved an excellent overall rating for its functional effectiveness (AWM=4.31, strongly agree). This high rating suggests that the integration of automatic drying and sanitation mechanisms efficiently meets users' expectations, confirming the prototype's ability to function as a useful device. The capacity to thoroughly dry the thick internal layers of washed shoes within 1 to 1.5 hours (M=4.68, strongly agree). Users underlined the device's reliability in keeping shoes dry on long, rainy days when there is no natural sunlight (M=4.18, agree). Keeping the footwear completely dry and sanitized greatly improves overall foot hygiene (M=4.23, strongly agree). These high ratings are a direct result of incorporating fluid dynamics and thermodynamic principles into the prototype's design. The internal blower, operating at 13,000 RPM, induces forced-air convection in the drying chamber measuring 50×35×50.7 cm. This fast, continuous air circulation breaks the stagnant boundary layer of moisture deep within the dense and foam lining of cleaned shoes, greatly enhancing convective mass transfer and moisture desorption compared to passive ambient drying. These assessments show that the device successfully replicates natural drying through indoor mechanization. The results of this study lend credence to the design optimization proposed by Mohsin et al. (2024) and the chamber designs proposed by Bowers et al. (2025), which suggest that accelerating the process of moisture reduction by maintaining constant air circulation in an enclosed space may be beneficial. The dual purpose of the device, which is drying and disinfecting, aligns with the guidelines of Belay et al. (2025) that integrating automated disinfection with user-centered design influences product acceptance.

The prototype's operational convenience received an excellent overall evaluation (AWM=4.37, strongly agree). This result demonstrates that the system enables users to operate the device without encountering technical difficulties. The highest assessment of the device was the effortless removal of its lower drain compartment to discard collected water without creating a mess (M=4.48, strongly agree). Users highly appreciated this ergonomic design feature because it prevents stagnant accumulation and maintains a clean immediate environment. Next to this, respondents strongly agreed that the digits on the countdown LED display are highly clear and visible even from a distance (M=4.45, strongly agree), providing precise visual feedback regarding the remaining cycle time. These two features reveal that effective mechanical drainage combined with clear visual tracking significantly increases user confidence. The result of the study is consistent with Chen et al. (2025), which states that the development of innovative devices with appropriate components enhances operating efficiency and safety. In this regard, Lucila (2026) further confirmed that hardware combinations influence operational trust. The electronic and manual control features received slightly lower evaluations but remained favorable with the users. Respondents concurred that setting the preferred operating time via the digital relay module makes it easy to set the desired working duration (M=4.33, agree). The lowest rating indicated that adjusting the speed controller knob provides full control of airflow intensity (M=4.20, agree), suggesting that users prefer automated over manual controls. Similarly, Mencias et al. (2024) showed that replacing traditional manual adjustments with user-friendly automated interfaces makes devices much more convenient to use.

The importance of these results lies in the fact that the physical interface directly affects how successfully a technical product is adopted in everyday life. This successfully eliminates the common problems associated with complex home devices by combining easy physical maintenance with real-time visual tracking. This user-centered design aligns with the automated evaluation models of Bezerra and Silva (2023), who demonstrated that directly aligning specialized equipment layouts with explicit user needs ensures long-term utility and functional reliability.

5. Conclusion

The development of the footwear hygiene prototype demonstrates its efficacy as a household alternative for fast moisture extraction of footwear. The integration of thermal airflow meets its operational goals by reducing conditions favorable to microbial growth that traditional washing methods cannot reach. This disinfection and rapid drying, thereby validate the design's structural capacity to serve as a highly practical household appliance. Under regulated conditions, the UV-C light system in the footwear chamber showed notable disinfection efficacy while operating at its calibrated UV-C radiation intensity. In a typical exposure cycle, it produced a significant reduction in the number of Staphylococcus aureus present on textile linings. This demonstrates empirically that it can be used as an additional method for disinfecting footwear without the need for harsh chemical treatments. Regarding the quality of moisture removal, the device removes moisture from wet materials at a constant, smooth rate. This efficient filtration and mess-free collection system during moisture extraction successfully meets the user's practical need for clean, dry, and ready-to-wear shoes without causing any household spills. In terms of functional effectiveness for sanitizing footwear, the prototype is a highly effective domestic solution for comprehensive sanitization. By fusing active thermal airflow with germicidal light, the system thoroughly dries thick materials within a short window, thereby preventing mold growth and completely eradicating odors on sunless, rainy days. The overall hardware configuration offers convenience to users. The user-friendly interface makes the technology easily accessible and highly practical for modern families to adopt.

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Conflict of Interest Statement

The authors of this study affirm that there are no conflicts of interest regarding the research, evaluation, and publication of this manuscript. The study was conducted purely for academic purposes, and all contributors listed on the title page have no relevant interests to disclose.

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