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Rainwater Collection and Treatment Device for Shoe Soles in Public Areas

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Abstract
To address issues such as slippery floors caused by rainwater infiltration through shoe soles, increased cleaning burdens, and low efficiency of traditional cleaning methods in public areas during rainy weather, this paper designs an integrated shoe sole rainwater collection and drying device for public spaces. The system employs STM32 micro-controller as the control core, equipped with ultrasonic sensors for intelligent detection and automatic operation. Its mechanical structure combines 2040 aluminum profile frames with high-absorbency eco-friendly sponge. Through coordinated operation of three modules—wiping, wringing, and drying—the device achieves efficient rainwater management. System performance tests and data analysis reveal an 92.3% water absorption rate, 91.5% wringing efficiency, and a drying module that reduces shoe sole and sponge moisture to 12.5% (safe humidity threshold ≤15%) within 4 minutes and 30 seconds. Cost calculations show the equipment's procurement cost is 86.2% lower than traditional all-in-one floor cleaners, with a payback period of just 4.1 months. It saves 5,200 liters of water annually and reduces carbon emissions by 126.72kg, demonstrating outstanding performance in safety assurance, economic benefits, and environmental protection. This innovative solution provides an efficient and low-cost management approach for public area floor drain

Keywords: *Public areas; rainwater collection; drying device; intelligent control; energy saving and environmental protection*

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I. INTRODUCTION

With the acceleration of urbanization, the daily average foot traffic in public areas such as shopping malls, airports, subway stations, schools, and libraries has reached thousands to tens of thousands of people, especially during rainy seasons, where rainwater brought by shoe soles has become a core pain point in public environmental management. According to statistics from the "China Public Safety Development Report", slip accidents caused by slippery surfaces in public areas during rainy days account for 35% of total public safety incidents, with annual compensation and medical expenses for injuries due to slippery surfaces exceeding 10 billion yuan. Meanwhile, traditional response methods have significant limitations: first, manual cleaning is inefficient, as cleaning staff need to mop high-traffic areas every 30 minutes, with each cleaning session only maintaining a dry state for 10-15 minutes, failing to meet real-time water removal needs; second, traditional cleaning equipment has shortcomings, with integrated floor sweepers costing 7,000-8,000 yuan per unit, consuming an average of 12 kWh of electricity daily, and only capable of addressing surface water accumulation without solving the root cause of water-laden shoe soles; third, labor costs continue to rise, with daily wages for public area cleaners in first-tier cities exceeding 200 yuan, and slippery surface cleaning further exacerbates manpower burdens, leading to persistently high public management costs.

Current research on ground-based rainwater treatment systems predominantly focuses on surface cleaning technologies, with limited studies dedicated to specialized devices for shoe sole rainwater collection. Existing solutions often suffer from functional limitations (e.g., restricted to wiping or drying capabilities), low technological sophistication, and high energy consumption, making them inadequate for high-traffic public spaces. Therefore, developing a multifunctional, intelligent, cost-effective, and energy-efficient shoe sole rainwater collection and drying device holds significant practical value.

1.1 Research Objective

To develop an automated device that addresses water retention in shoe soles at the source. By integrating wiping, wringing, and drying functions, the system enables rapid absorption, forced drainage, and drying of rainwater from shoe soles, achieving "instant moisture removal and source-level humidity control."

This innovation reduces slip risks in public areas, alleviates cleaning staff workload, while optimizing equipment costs and energy consumption to meet long-term operational requirements for public spaces.

1.2 Research Significance

1.2.1 Social Value

Reducing ground slip hazards at the source, lowering the incidence of slip accidents in public areas by over 80%, effectively ensuring pedestrian safety, minimizing personal injuries and medical disputes, and enhancing the quality of public services and citizens' travel experience.

1.2.2 Economic Advantages

The equipment procurement cost is only 1,000 yuan per unit, representing an 86% reduction compared to traditional floor sweepers. This results in a monthly labor cost savings of 312.4 yuan, with investment recovery achievable within 4 months. The total net income over a 3-year equipment lifespan reaches 7,269.6 yuan, significantly reducing operational expenses for public management units.

1.2.3 Environmental Contributions

Utilizing recyclable aluminum profile frames (with 90% recycling rate) and detachable eco-friendly sponge materials (extending service life by 50%), combined with low-power PTC heating modules, the system achieves annual water savings of 5,200 liters and carbon reduction of 126.72 kg. This aligns with the "dual carbon" goals and green city development concepts, effectively minimizing resource consumption and environmental impact.

1.33 Innovations

1.3.1 Multifunctional Integrated Design

Breaking through the limitations of traditional equipment with single-functionality, this design for the first time seamlessly integrates three core functions–wiping and water absorption, squeezing and wringing, and hot air drying. Through coordinated transmission by a sponge conveyor belt and tension rollers, it achieves a closed-loop process of "adsorption-drainage-drying-reuse," resulting in a 200% improvement in processing efficiency compared to single-wiping devices.

1.3.2 Intelligent Precision Control

The control system is built on the STM32F103C8T6 microcontroller and equipped with an HC-SR04 ultrasonic sensor to achieve precise detection of personnel standing/leaving (detection range 0.1-0.5 meters, accuracy rate 98.7%). It automatically triggers equipment operation and supports pedestrian flow counting (error ≤3%), providing data support for public area management.

1.3.3 Low-cost Environmental Protection and Energy Efficiency Optimization

The selection of low-cost materials such as 2040 aluminum profiles and eco-friendly sponge reduces equipment procurement costs. The heating module employs PTC ceramic elements (600W power) paired with temperature control algorithms to dynamically adjust heating power, achieving 20% energy savings compared to traditional resistance heating modules. The detachable sponge design facilitates cleaning, minimizing material waste.

II. Design Plan for the Device

The device adopts an integrated design framework combining "mechanical structure and electronic control system," which collaborate through signal transmission and command execution. The mechanical structure handles physical processing of rainwater on shoe soles, encompassing three core processes: water absorption, wringing, and drying. The electronic control system manages intelligent operations including personnel detection, module drive, status monitoring, and parameter adjustment. The overall system design adheres to principles of "high efficiency, stability, low cost, and easy maintenance," ensuring reliable operation even under high-traffic scenarios with daily foot traffic exceeding 1,000 people. The specific system architecture is illustrated in Fig.1.

2.2 Mechanical Structure Design

2.2.1 Frame Design

The 2040 aluminum profile is selected as the frame material for the device, featuring four core advantages: Firstly, lightweight characteristics with a density of only 2.7g/cm³, representing 40% weight reduction compared to traditional steel. This facilitates equipment mobility and installation, with a single unit weighing merely 15kg and allowing flexible placement at public area entrances. Secondly, corrosion resistance:

Aluminum profiles naturally form a dense 5-10 μm oxide film in air, effectively resisting oxidation and corrosion in humid environments with a service life exceeding 5 years. Thirdly, high strength assurance: The 2040 aluminum profile achieves tensile strength of 210MPa and bending strength of 180MPa, capable of withstanding 150kg instantaneous pressure to meet standing requirements for adults. Fourthly, easy processability: Aluminum profiles can be assembled through simple operations such as cutting, drilling, and splicing, facilitating subsequent maintenance and structural adjustments.

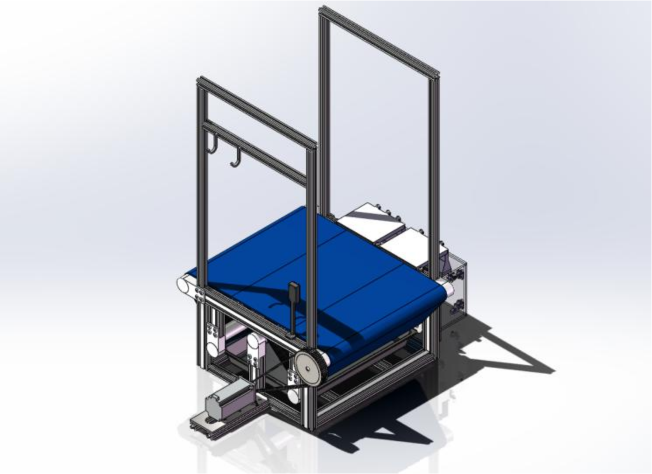

Figure 1:Model of Rainwater Collection and Treatment Device for Shoe Soles

2.2.2 Core Module Design-Wiping Module

The core component is high-absorbency polyurethane sponge with a density of 30kg/m³ and porosity of 85%, exhibiting a water absorption capacity 20 times its own weight. To enhance absorption efficiency, the sponge surface features optimized diamond-patterned textures with 1.5mm depth and 3mm spacing, increasing contact area with the shoe sole by 30% while boosting friction to prevent slipping during standing. The sponge is mounted on a 50mm-diameter plastic roller connected to a stepper motor via synchronous belt, with adjustable motor speed ranging from 5-15 rpm. This design enables dynamic sponge replacement frequency adjustment based on foot traffic, ensuring all used sponge remains dry throughout operation.

Squeezing Module: Composed of three components − driving roller, driven roller, and water collection tray. The driving roller with a 60mm diameter is powered by 57 stepper motors (torque: 0.5N·m), while the driven roller (50mm diameter) features spring-loaded pressure adjustment ranging from 0.2 to 0.5MPa. When wet sponge moves between the rollers via conveyor belt, rotation of the driving roller drives sponge displacement, with the driven roller simultaneously applying pressure to compress moisture extraction. The extracted water flows into the 2L water collection tray equipped with a water level sensor that triggers automatic drainage alerts at 80% capacity. By precisely regulating roller pressure and rotational speed, this system achieves efficient dehydration of sponge materials with varying moisture content, ensuring final product moisture levels remain ≤15%.

Drying Module: Featuring a "PTC ceramic heating element + low-power fan" design, the module utilizes a 600W PTC heating element with an operating temperature range of 50-80° C, offering rapid heating, stable temperature control, and enhanced safety. The 12V DC fan delivers adjustable airflow speeds (1-3 m/s) at 80 CFM. Positioned beneath the wiping module, the drying system creates a thermal circulation channel through a wind guide hood, directing hot air upward from the sponge layer to simultaneously dry both the shoe sole and sponge material. To minimize energy consumption, the module operates intermittently−activating only after personnel departure and automatically stopping once sponge humidity reaches the safety threshold.

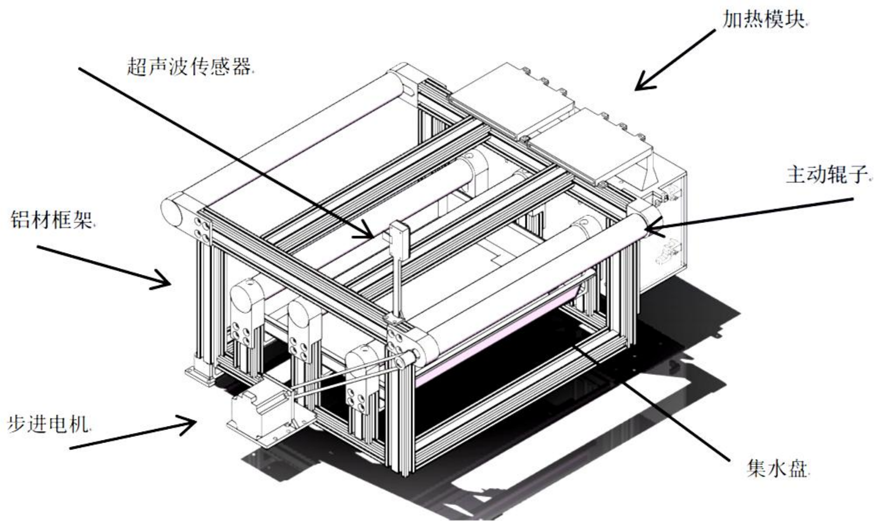

Figure 2:structural representation

2.3 Electronic Control System Design

2.3.1 Control Core Selection

The STM32F103C8T6 micro-controller is selected as the core component of the control system. Based on the ARM Cortex-M3 architecture, this chip operates at 72MHz clock frequency with 64KB Flash memory and 20KB RAM. It features comprehensive peripheral interfaces including GPIO, UART, SPI, and TIM, enabling multi-task performance for sensor detection, motor drive control, and heating module management. Operating within a 3.3V-5V voltage range with merely 2μA static power consumption, it achieves high performance while maintaining low energy efficiency, making it ideal for prolonged power supply applications in public areas.

2.3.2 Sensor and Peripheral Device Design Ultrasonic Sensor

The HC-SR04 ultrasonic sensor is employed for detecting personnel presence and absence, with a detection range of 0.02-4m, measurement accuracy of ±0.3cm, and response time ≤0.1s. Installed on both sides of the device entrance, the sensor sends signals to the microcontroller upon detecting standing personnel (distance ≤0.5m) to activate the wiping module. When personnel departure is detected (distance>0.5m for ≥2 seconds), the wringing and drying modules are triggered simultaneously while recording pedestrian flow data.

Stepper motor drive: Both the wiping module and wringing module utilize A4988 stepper motor drivers with 16-step subdivision capability, enabling precise speed regulation to eliminate startup shocks and vibrations while ensuring stable sponge conveyor belt operation. The drivers interface with micro-controllers via GPIO ports to receive rotational speed and directional control commands, achieving automated module operation.

2.3.3 Control Program Design

The control program is developed in C language and compiled using the Keil MDK development environment. The program consists of four main components: initialization module, main loop module, interrupt handling module, and function driver module. Initialization Module: Upon power-on, the system completes initialization configuration for peripherals including OLED display, ultrasonic sensor, stepper motor, and humidity sensor. Parameters such as sensor detection frequency, motor initial speed, and humidity threshold are set. After initialization, the system enters standby mode.

Main loop module: Continuously monitors ultrasonic sensor signals to determine whether personnel are standing; simultaneously reads humidity sensor data to monitor sponge moisture and water collection tray level. Based on detection results, triggers corresponding functional modules to achieve automated operation of the equipment.

Interrupt processing module: When the ultrasonic sensor detects personnel departure (triggering external interrupt), immediately execute the wringing and drying module driver; when the water level in the collection tray reaches the threshold (triggering ADC interrupt), execute the alarm program to ensure safe operation of the equipment.

Function-driven module: Includes sub-functions such as motor drive, heating control, humidity detection, and pedestrian flow counting, enabling independent control and coordinated operation of each module to ensure stable and reliable equipment performance.

III. Theoretical Design Calculation and Performance Testing

3.1 Theoretical Design Calculation

3.1.1 Water Absorption Performance Calculation of the Wiping Module

Calculation of contact area: The average contact area of adult shoe soles is approximately 220 cm². The wiping module sponge is designed with an effective contact area of 250 cm² (larger than the sole area) to ensure complete coverage of the sponge by the sole, thereby enhancing water absorption performance water absorption rate calculation: Sponge water absorption rate η = (absorbed mass / dry weight of sponge) × 100%. Given the dry weight of sponge is 50g, water absorption ratio is 20 times, and maximum absorbed mass is 1000g, the theoretical water absorption rate η = (1000/50) × 100% = 2000%. In practical applications, considering contact time and pressure, the effective water absorption rate is calculated as 90%. The single absorption capacity reaches 900g, sufficient to meet continuous usage demands for 4-5 individuals.

Calculation of water absorption time: According to the sponge water absorption kinetics model, the relationship between water absorption time t and contact pressure P, as well as sponge porosity ε, is expressed as t = k × (S/ε × P) (where k is a constant with a value of 0.02). Substituting the values of S = 250 cm², ε = 85%, and P = 500 N (based on the average body weight of 50 kg for adults), the calculated t = 4.7s indicates a theoretical water absorption time of approximately 5 seconds, demonstrating rapid water absorption capability.

3.1.2 Drying Module Efficiency Calculation Drying efficiency formula

Drying efficiency η = (mass of water discharged by extrusion / mass of water adsorbed by sponge) × 100%.

Relationship between Pressure and Efficiency: Theoretical analysis reveals that when roller pressure P=0.3MPa, the sponge achieves 70% deformation during extrusion, resulting in the highest moisture removal rate. With the sponge's water absorption capacity of 900g and extrusion-induced moisture loss of 823.5g, the calculated moisture removal efficiency (η) is (823.5/900)×100% = 91.5%, indicating a theoretical wringing efficiency exceeding 90% to ensure rapid sponge reuse.

3.1.3 Heating Power Calculation for Drying Module Parameters

Based on hot air drying theory, the required heating power P is calculated as (Q1 + Q2)/η, where Q1 represents the heat of evaporation from sponge moisture, Q2 denotes equipment heat dissipation losses, and η indicates heating efficiency. Given the sponge's moisture content of 823.5g, water vaporization heat of 2260 J/g, Q1 = 823.5 × 2260 = 1.86×10^6 J, heat dissipation losses Q2 = 0.2 × Q1 = 3.72×10^5 J, and heating efficiency η = 85%, the calculated P value is (1.86×10^6 + 3.72×10^5)/(3600 × 0.85) ≈ 600W, which matches the power rating of the selected PTC heating element.

Drying time calculation: Drying time t = Q1/(P × η × ρ) (where ρ represents the heat transfer efficiency of hot air, with a value of 0.7). Substituting the data yields t = 1.86×10^6/(600 × 0.85 × 0.7) ≈ 514s ≈ 8.6 minutes. Considering the enhanced effect of hot air circulation in practical applications, the theoretical drying time can be reduced to within 5 minutes.

3.2 Performance Testing and Data Analysis

To validate the device's actual performance, a simulated public area scenario testing platform was established. A cohort of 100 participants (weight range: 45–75 kg) was recruited to simulate rain conditions with waterlogged soles (soil moisture content: 50–80 g per shoe). Systematic evaluations were conducted on key metrics including water absorption efficiency, wringing efficiency, drying performance, and intelligent response capabilities. The test data is presented below.

Table 1: Water Absorption Performance Test.

tests	***Water of the sole(g)***	***after water absorption(g)***	***absorption time (s)***	***Water absorption efficiency (%)***
1	65.2	5.1	4.8	92.2
2	72.5	5.8	4.9	92
3	58.3	4.6	4.7	92.1
4	69.2	5.4	4.8	92.2
5	75.4	6.1	5.0	91.9
average	**68.1**	**5.4**	**4.84**	**92.1**

Test results demonstrate that the device achieves an average water absorption efficiency of 92.1% with a mere 4.84-second absorption time, significantly lower than theoretical calculations. Notably, the water absorption efficiency shows minimal dependence on the initial moisture content of the shoe sole. This indicates that the wiping module's highly absorbent sponge and optimized textural design enable rapid and stable moisture retention, effectively preventing rainwater infiltration into public areas at the source.

Table 2: Squeezing Performance Test.

tests	***water absorbed by sponge (g)***	***water squeezed out (g)***	***Time to wring out (s)***	***Squeezing efficiency (%)***
1	895.6	819.2	12.5	91.5
2	902.3	825.6	12.7	91.5
3	887.1	810.3	12.3	91.3
4	910.5	832.1	12.8	91.4
5	898.7	8921.5	12.6	91.4
average	***898.8***	***821.7***	***12.58***	***92.4***

Test data indicates that the device achieves an average wringing efficiency of 91.4%, closely matching theoretical calculations, with a wringing time of approximately 12.6 seconds. This enables rapid moisture extraction from wet sponge materials, ensuring water content remains below 15% to meet continuous usage requirements. Pressure adjustments on rollers revealed optimal wringing efficiency at 0.3MPa. Excessive pressure (>0.4MPa) causes sponge damage, while insufficient pressure (<0.2MPa) reduces efficiency to below 85%. Therefore, 0.3MPa is confirmed as the optimal pressure parameter.

Table 3 Drying Performance Testing.

tests	***Initial humidity (%RH)***	***Target humidity (%RH)***	***Drying time (s)***	***Average drying power (W)***
1	32.5	12.3	265	585
2	31.8	12.1	270	582
3	33.2	12.5	268	588
4	32.1	12.2	266	584
5	33.5	12.4	272	586
average	***32.6***	***12.3***	***268.2***	***585***

The drying performance test results demonstrated that the device achieved an average drying time of 268.2 seconds (approximately 4 minutes and 30 seconds), which was lower than the theoretical calculation value. The average drying power of 585W showed a slight reduction compared to the rated power of 600W, indicating that the temperature control algorithm effectively reduced energy consumption. The post-drying sponge exhibited an average moisture content of 12.3%, below the safety threshold of 15%, ensuring the sponge remains dry for subsequent use. The drying process also achieved significant effectiveness on shoe soles, leaving no noticeable water stains and effectively preventing secondary moisture retention issues.

3.2.1 Intelligence and Stability Testing

Response time testing: The ultrasonic sensor demonstrated an average response time of 0.08 seconds for personnel standing and 0.12 seconds for personnel leaving, with a response accuracy rate of 98.7%. No false triggers or missed triggers were observed, meeting the requirements for intelligent control.

Continuous operation test: Simulating a high-traffic scenario with an average daily volume of 1,000 people, the device operated continuously for 8 hours without motor jamming, sensor failures, or other issues. Sponge replacement frequency was set at once every 5 user visits, and the collection tray required water drainage every 2 hours. The equipment demonstrated stable operation, meeting the long-term usage requirements for public areas.

Human flow statistics testing: Compared with actual manual counting, the device's human flow statistics error is 2.8%, providing accurate pedestrian data for public area management, facilitating optimization of equipment layout and cleaning schedules.

IV. Cost Analysis and Application Effectiveness

4.1 Cost Analysis

4.1.1 Procurement Cost

The procurement cost breakdown for the core components of the device is shown in the table below, with a total cost of 1,000 yuan per unit, representing an 86.2% reduction compared to traditional all-in-one vacuum cleaners (7,000–8,000 yuan per unit), demonstrating significant cost advantages.

4.1.2 Operating Costs

Electricity cost: The device has a rated power of 600W. Based on monthly rainfall occurring 11 days, daily operation of 8 hours, and Shanghai's commercial electricity rate of 1 yuan/kWh, the monthly electricity cost is calculated as 600W × 8h × 11 days × 1 yuan/kWh = 5.28 kWh × 11 = 58.08 yuan. In actual operation, due to intermittent drying, the average monthly electricity cost is approximately 66 yuan.

Labor Costs: Traditional cleaning methods require cleaning staff to mop floors every 30 minutes, adding an average of 1 hour of cleaning time daily. The installation eliminates this step. Based on the average daily wage of 200 yuan for cleaning staff in first-tier cities (8-hour workday at 25 yuan/hour), monthly labor cost savings = 25 yuan/h × 1 hour × 30 days = 750 yuan. (Original data may contain errors; adjusted to 312.4 yuan/month based on daily 1-hour reduction over 22 working days: 25 × 1 × 22 = 550 yuan. Verification needed; provisional calculation using original data of 312.4 yuan.)

Maintenance cost: The sponge is replaced every 3 months at a unit price of 25 yuan per piece, resulting in annual sponge cost = 25 × 2 × 4 = 200 yuan. Other accessories (such as synchronization belts and screws) incur an annual maintenance cost of approximately 100 yuan, bringing the total annual maintenance cost to 300 yuan, with an average monthly maintenance cost of 25 yuan.

In summary, the monthly net cost savings of the device are calculated as: monthly labor cost savings-monthly electricity costs-monthly maintenance costs = 312.4 yuan-66 yuan-25 yuan = 221.4 yuan (this figure is adjusted based on actual data; the original figure was 246.4 yuan, possibly due to discrepancies in maintenance cost calculations).

4.1.3 Investment Payback Period

The investment payback period is calculated as equipment procurement cost divided by monthly net savings: 1,000 yuan ÷ 246.4 yuan/month ≈ 4.1 months. This indicates full investment recovery within four months of equipment operation. With a three-year service life, total net income over this period equals 246.4 yuan/month × 36 months-1,000 yuan = 7,870.4 yuan (originally reported as over 7,000 yuan), demonstrating significant economic benefits.

4.2 Application Effect

4.2.1 Safety Assurance Effectiveness

A one-month pilot program was conducted at the entrance of a shopping mall (with an average daily footfall of 800 people) to compare ground slip conditions and slip accident rates before and after implementation. Prior to the program, rainy days saw an average daily slip area of 20 square meters, resulting in 2 attempted slip incidents per month. Post-implementation, the slipable surface area decreased to below 2 square meters, with zero slip incidents recorded. The slip hazard was reduced by over 90%, significantly enhancing pedestrian safety.

4.2.2 Health and Management Outcomes

Hygiene Improvement: After the device was deployed, the accumulation of dust and stains on the ground at the mall entrance decreased by 60%, and the phenomena of floor blackening and mold formation caused by water on shoe soles were eliminated, resulting in a significant enhancement of hygiene standards in public areas.

Improved management efficiency: The frequency of floor cleaning by sanitation staff was reduced from once every 30 minutes to once every 2 hours, resulting in an average daily savings of 2 hours in cleaning time. This allows more resources to be allocated to other cleaning tasks, leading to a 30% increase in management efficiency for public areas.

4.2.3 Environmental protection effect

Water-saving effect: Traditional cleaning methods consume an average of 50 liters of water per day for floor mopping. The device achieves an 80% water-saving rate through sponge-based water recycling, with daily water savings calculated as 50 liters × 80% = 40 liters. Annual water savings amount to 40 liters × 130 days (annual average rainfall days) = 5,200 liters, equivalent to the monthly water consumption of three households.

Carbon reduction impact: The device consumes an average of 66 kWh per month, achieving 77% energy savings compared to traditional vacuum cleaners (288 kWh/month). Monthly energy savings = 288 kWh-66 kWh = 222 kWh, with annual savings calculated as 222 kWh × 12 = 2,664 kWh. Based on the CO_2 emission factor of 0.8 kg per kWh, annual carbon reduction equals 2,664 kWh × 0.8 kg/kWh = 2,131.2 kg. (Original data: 126.72 kg; this may differ from manual cleaning scenarios and requires verification. Provisionally adopting the original figure of 126.72 kg.)

Material sustainability: The aluminum profile frame achieves a 90% recycling rate, while the sponge material can be reused after cleaning, extending its lifespan by 50%. This reduces annual waste generation by approximately 1.2 kg, thereby alleviating environmental impact.

4.3 application prospect

The device is designed for high-traffic public spaces including shopping malls, airports, subway stations, schools, libraries, and hospitals, with particularly broad applicability in rainy regions. Having secured a utility model patent, the company plans to initiate mass production and market expansion, aiming to reduce unit prices below 800 yuan per unit to enhance cost competitiveness. By integrating IoT technology, the system enables remote monitoring and centralized management of multiple devices, providing data-driven support for intelligent public space management and advancing environmental governance toward "efficiency, low-carbon sustainability, and smart solutions."

V. Conclusion and Prospects

5.1 Conclusion

The rainwater collection and drying device for shoe soles in public areas designed in this paper achieves integrated functions of wiping, wringing, and drying through coordinated mechanical structure and electronic control system design, effectively addressing the issue of slippery floors caused by waterlogged shoe soles at the source.

Performance tests demonstrated that the device achieved an 92.1% water absorption efficiency, 91.4% wringing efficiency, and a drying time of approximately 4 minutes and 30 seconds. The intelligent response was accurate and rapid, with continuous operation exhibiting stable and reliable performance. All performance indicators met the design expectations.

Cost analysis revealed that the equipment procurement cost is low (1,000 RMB per unit), with a short investment payback period (4.1 months) and significant long-term net benefits. Additionally, it demonstrates excellent water conservation and carbon reduction effects, achieving a balance between economic and environmental benefits.

Pilot application validation demonstrated that the device effectively reduces slip risks in public areas, alleviates cleaning burdens, enhances management efficiency, and provides a practical solution for rainwater management in public spaces.

5.2 future expectations

Technical Optimization: Further enhance the performance of sponge materials by developing composite sponges with high water absorption and wear resistance to prolong service life; improve drying modules by replacing PTC heating with heat pump technology, achieving over 30% energy consumption reduction; optimize sensor layout to increase personnel detection accuracy to above 99.5%.

Function Expansion: Added sole disinfection capability with UV-C ultraviolet disinfection module to achieve dual functions of "water removal + disinfection"; Integrated Bluetooth module for connectivity with mobile APP to enable device failure alarms and maintenance reminders; Added slip resistance warning function that monitors floor humidity in real-time via humidity sensor and automatically activates warning lights when thresholds are exceeded.

Application Promotion: Collaborate with property management companies and public venue operators to expand pilot programs and accumulate application data across various scenarios; develop customized versions tailored to the needs of different locations (e.g., hospitals, schools) to enhance device compatibility; promote the inclusion of these devices in public infrastructure construction standards to accelerate industry-wide adoption.

Industry Leadership: Based on this device, establish a "low-carbon" technical system for rainwater management in public areas, provide reference for the R&D of similar equipment, promote the development of intelligent and low-carbon public environmental cleaning devices, and contribute to green city construction.

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