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Design of Automatic Cloth Drying Tube Machine

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Abstract: The paper presents the Automatic Cloth Drying Tube Machine (ACDTM), an innovative solution designed to tackle the persistent challenge of efficient cloth drying, particularly under adverse weather conditions. The primary objective is to mitigate the discomfort associated with wearing damp clothing by utilizing an automated electronic system to achieve effective garment drying. The device operates by channeling a downward stream of heated air through a tube, ensuring rapid and thorough drying of clothes suspended within the system, thereby reducing reliance on conventional natural drying methods. Efficient cloth drying remains a global challenge due to climatic variations, urban residential constraints, and adverse weather conditions. Urban areas, characterized by high population density and limited living spaces, often lack adequate room for traditional drying methods, compounded by insufficient sunlight exposure due to tall buildings or other obstructions. The proposed machine ACDTM addresses these challenges with an advanced electronic system that incorporates an AC 220V turbofan, an LED strip, and an XH W3001 thermostat equipped with a soil moisture sensor. This compact system is specifically designed for confined spaces, making it ideal for urban environments. It eliminates the need for outdoor drying, particularly in pollution-prone areas, and ensures efficient and hygienic drying in regions with high humidity. The automated mechanism detects moisture levels in clothes, optimizing energy consumption and enhancing user convenience. The inclusion of digital thermostat technology allows for precise temperature adjustments to match fabric quality, ensuring safe and efficient drying operations tailored to various fabric types.

Keywords: Automation, System, Tube, Sensor, Dryer, Electronic

1. INTRODUCTION

The invention of the first electric dryer dates back to the early 20th century. Inventor J. Ross Moore, seeking a solution to the inconvenience of hanging clothes outdoors, particularly in winter, constructed a shed equipped with a stove for indoor drying. This setup, where clothes were hung in front of the fire to dry, marked the initial phase of electric dryer development. Over the next three decades, Moore endeavored to design a gas and electric unit but struggled to find a manufacturer. Eventually, the drum-type model he developed was adopted by Hamilton Manufacturing in Wisconsin and marketed under the name June Day, starting in 1938.

A clothes dryer, commonly referred to as a tumble dryer, is an electrically powered household appliance designed to remove moisture from textiles, including clothing and bedding, typically following their washing. While traditional drying methods involve natural evaporation, often facilitated by sunlight on outdoor or indoor clotheslines, these methods can lead to color fading of fabrics.

Globally, cloth drying poses significant challenges due to climatic variations, residential limitations in urban environments, and adverse weather conditions such as heavy monsoon rains. Effective drying solutions are critical, especially in situations where clothes remain damp despite extended outdoor drying periods. Urban areas, characterized by high population density and limited living spaces, often lack the necessary room for traditional drying equipment. Furthermore, inadequate sunlight exposure, caused by tall buildings or other obstructions, exacerbates the drying process, underscoring the need for alternative drying technologies [1].

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Most West African countries, including Ghana, Nigeria, Sierra Leone, Côte d'Ivoire, and The Gambia, experience a tropical climate characterized by distinct rainy and dry seasons. In particular, Ghana exhibits a typical tropical monsoon climate with an annual rainfall of approximately 750 mm. The inevitable rainy seasons and high humidity levels pose significant challenges to daily activities, especially for drying clothes. During the rainy season, the unpredictability of weather changes complicates the drying process, as washed clothes left on lines by working adults and students often get repeatedly soaked by rain, leading to extended drying times. This delay affects daily routines and limits wardrobe choices.

Existing drying solutions, such as hot drying racks, electric laundry dryers, irons, hydro laundry systems, and outdoor drying racks, either lack smart features or are prohibitively expensive to install and maintain. Moreover, these methods can damage fabrics easily. In contrast, the United States predominantly uses electric dryers, consuming about 16 billion kW annually, which accounts for 5.8% of total residential electricity consumption. Applying this level of electricity consumption to West Africa would be financially burdensome for the average student or working adult [2].

In Nigeria, the high cost and limited availability of imported dryers have highlighted the demand for an affordable, locally fabricated solution. Addressing this, the Department of Mechanical Engineering Technology at the Federal University of Technology, Akure, developed a cost-effective cloth drying machine utilizing locally sourced materials. This dryer is designed for efficient and affordable domestic use across various fabric types, achieving an average drying rate of 0.4 to 1.2 g/min, which indicates effective moisture removal. There is performance variability due to the quality of local materials and notable energy consumption, the dryer presents substantial benefits, including affordability, accessibility, and support for the local economy. These factors make it a viable solution for meeting domestic fabric drying needs in Nigeria [3].

Upon surveying various papers, details regarding multiple methods of drying clothes were found.

In their study, Suchitkumar AN et al. discuss the Quick Portable Cloth Drying Machine, emphasizing its use of a high-efficiency blower to achieve significant energy savings of 30-50% and lower cloth temperatures compared to conventional electric dryers. The machine's straightforward and cost-effective design makes it easy to manufacture and operate without the need for specialized labor, enhancing its portability. Future enhancements include the integration of speed controllers, time controllers, and moisture sensors to enable automation. However, challenges remain, such as the need for further optimization for real-time control and addressing potential efficiency gaps relative to more advanced models. Despite these challenges, this innovation addresses the urgent demand for energy-efficient and aesthetically pleasing drying solutions in urban residences with limited space [4].

The study conducted by Chailoet A et al. provides a comprehensive analysis of rapid cloth drying processes through both mathematical modeling and experimental data. It underscores the impact of key factors such as air temperature, humidity, and the mass transport coefficient on drying efficiency. The primary technology examined is a rapid cloth drying heat pump, which significantly reduces drying time to 12 minutes with a COP of 5.4, compared to the traditional outdoor drying time of 2-3 hours under sunny conditions. The research identifies the mass transport coefficient, which can be adjusted via airspeed, as the most critical factor for optimizing drying periods. Despite the impressive results, the study acknowledges limitations, including the need for real-time control and further investigation into the precise relationship between air speed and drying efficiency. The findings advocate for the development of efficient, rapid cloth-drying technologies that are suitable for various climates and urban settings [5].

In the study conducted by Obanoyen ON et al., a cloth drying machine was designed and fabricated to mitigate the challenges associated with traditional cloth drying methods. Utilizing locally sourced materials, the machine effectively removes moisture at an average drying rate of 0.4 to 1.2 g/min, accommodating various fabric types. While the machine is affordable and well-suited for domestic use, its reliance on electricity and potential economic barriers for low-income households, particularly in regions like Nigeria, pose limitations. Despite these challenges, this innovation provides a practical solution for households seeking an alternative to natural cloth drying, particularly during adverse weather conditions [3].

In their project, inspired by the challenges of drying clothes during rainy seasons, Jadhav R et al. developed a Clothes Dryer Machine with a focus on low-cost, energy-efficient, and compact design. The machine addresses the limitations of traditional dryers by incorporating features such as fabric type adjustment for heat and fan speed, humidity sensors to determine drying status, and potential future enhancements like image processing and machine learning for further optimization. While the machine offers rapid drying and reduced user effort, potential drawbacks include the complexity of sensor integration and maintenance, as well as challenges in achieving optimal fabric drying without causing damage. Overall, the project presents promising advancements in clothes-drying technology [1].

In their paper, Kalyankar AN et al. present an innovative design that combines a cloth dryer and dehydrator into a single unit, addressing both clothing and food drying needs. The machine is equipped with temperature controllers to maintain desired heat levels and fans to ensure uniform heat distribution. Testing demonstrates efficient dehydration of various food items within specific time frames and temperatures while achieving clothes drying within 20-25 minutes. This dual-purpose approach offers versatility and convenience, optimizing both space and energy usage. However, potential limitations include operational and maintenance complexity, as well as the necessity for precise temperature control to avoid damage to both textiles and food items. Overall, the integration of cloth drying and food dehydration technologies represents a significant advancement in drying efficiency [6].

To address the challenges identified in the survey, the proposed Electronic Drying Tube Machine features an advanced electronic system incorporating an AC 220V turbofan and LED strip, controlled by the XH W3001 thermostat with soil moisture sensor. This compact system is specifically designed for deployment in confined spaces, offering a practical solution to urban cloth drying challenges. By eliminating the need for outdoor drying, particularly in pollution-prone areas where clothes are susceptible to rapid soiling, the machine reduces the frequency of laundering. Additionally, in regions with high humidity levels, which extend drying times and promote unpleasant odors and mildew growth, the system ensures efficient and hygienic cloth drying.

This presented model integrates an automated mechanism that regulates the drying process by detecting moisture levels in clothes hung on the tube, thus optimizing energy consumption and enhancing user convenience. Utilizing digital thermostat technology, users can adjust temperature settings to match the fabric quality, ensuring safe and efficient drying operations.

The structure of this paper is organized as follows: Section I provides an introduction. In Section II, the drying system methodology is described, detailing the functionality of the components and including a connection diagram that illustrates the integration of these components. Section III outlines the system's workflow for the drying process. Section IV describes the model's architecture. The results obtained from testing the dryer are presented in Section V. Section VI contains the discussion, and concluding remarks are provided in Section VII.

2. DRYING SYSTEM METHODOLOGY

This section includes the connection diagram with the functionality of the components.

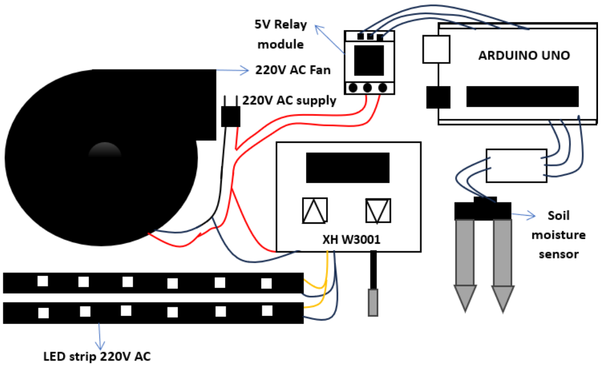

Fig. 1 Connection diagram of model

Figure 1 presents a connection diagram detailing the integration of various components. These include a soil moisture sensor, an AC 220V digital thermostat (XH-W3001), an AC 220V turbofan, and an LED strip. These components are interfaced with the development board through a 5V relay module.

The functionality of the components is mentioned below.

A. *Soil moisture sensor*

The soil moisture sensor is a sophisticated device designed to measure soil moisture content accurately. It consists of several key components: probes, a circuit board, and output pins. The probes are two conductive metal rods inserted into the soil to measure its resistance. The circuit board houses the electronics necessary to convert the analog signals from the probes into readable digital or analog outputs. The sensor typically operates on a 5V power supply, which powers the entire system.

The soil moisture sensor operates by inserting conductive probes into the water, measuring its resistance to determine moisture content. It converts analog signals to readable outputs via a circuit board, providing analog and digital outputs. Utilizing Ohm's Law in a voltage divider circuit, the sensor calculates resistance, which is calibrated to correlate voltage readings with moisture levels [7][8].

B. *XH W3001 digital thermostat*

The XH-W3001 temperature controller is a digital device designed for precise temperature regulation. It features programmable settings and integrates a relay for controlling external devices like LED strips. Operating with a 220V AC power supply, it uses a 10k NTC thermistor to monitor temperatures accurately within -

50°C to 100°C, with an accuracy of +/-0.1°C. Users can set heating thresholds by adjusting start and stop temperatures via simple button commands, making it straightforward for various heating applications.

To activate the heating mode, the following steps are mentioned.

1. Hold down the down arrow button for 3 seconds to set the min temperature.
2. Adjust the temperature using the up/down arrows and wait 5 seconds to confirm.
3. Hold the up-arrow button for 3 seconds to set the max temperature.
4. Adjust the temperature using the up/down arrows and wait 5 seconds to confirm.

The system checks ambient temperature; if below max °C, it activates the relay to heat the connected device. As the temperature nears or exceeds max °C, the relay turns off, allowing temperature to drop. When it reaches min °C, the relay reactivates to resume heating. This cycle repeats until power is interrupted [9][10][11].

C. AC 220V Turbofan

The AC 220V turbo fan constitutes a fundamental element within the proposed Electronic Drying Tube Machine, serving to optimize air circulation for the drying procedure. Its internal structure typically encompasses a motor, fan blades, housing, and wiring system. Functionally, the motor functions as the prime mover, transforming electrical energy from the AC power supply into mechanical energy to propel the fan blades. Crafted from durable materials such as plastic or metal, these blades are strategically positioned within the housing to induce a robust airflow.

Operationally, the AC 220V turbo fan operates through the conversion of electrical energy into kinetic energy. Upon connection to a 220V AC power source, the motor initiates rotation, prompting the fan blades to rotate rapidly. The rotational motion creates a zone of low pressure behind the blades, facilitating the intake of air from the surroundings. Subsequently, the rotating blades propel this ingested air forward, generating a potent airflow [12][13][14][15].

D. AC 220V LED strip

A 220V AC LED strip with plastic coating typically refers to an LED strip that operates directly on 220V AC mains voltage without needing a separate transformer or driver. The plastic coating serves as insulation and protection for the LED circuitry, making it suitable for indoor and outdoor applications where durability and safety are important. These strips are convenient for installation and can be cut to custom lengths as needed, providing efficient and bright lighting solutions in various environments.
A 220V AC LED strip with a plastic coating generates heat mainly through two mechanisms.

Firstly, LEDs convert electrical energy into light, but some are inevitably converted into heat due to inefficiencies in the LED chips and associated electronics. This internal heat generation is inherent to their operation.

Secondly, resistors used for current regulation or voltage adjustment in the LED strip also dissipate energy as heat. If these resistors lack adequate heat dissipation, their temperature can rise further [16].

E. 5V Relay module

A relay module acts as a switch controlled by an electromagnet. It bridges low-power control signals, like those from a microcontroller, with high-power devices. When triggered by a low-power signal, the relay's electromagnet either opens or closes the circuit, determining if the connected device receives power (ON) or not (OFF). The relay toggles between Normally Closed (NC) and Normally Open (NO) states based on its energized or de-energized condition. This setup enables safe control of high-powered devices using low-power signals, ensuring efficient and reliable operation across various electrical applications [17].

F. Arduino Uno

The Arduino Uno is a versatile microcontroller board based on the ATmega328P processor, operating at 16 MHz. It features 14 digital input/output pins and 6 analog input pins, making it capable of interfacing with a wide range of sensors and devices. Powered via USB or an external source, it supports easy programming through the Arduino IDE, utilizing C/C++ syntax [18].

3. WORKING

This section explains the system's workflow.

The clothes-drying system utilizes a soil moisture sensor to monitor fabric moisture content, as shown in Figure 2. The system is programmed with a 15% moisture threshold to control the drying process. The sensor detects fabric wetness by measuring conductivity with probes placed at the desired location. The core functionality relies on the formula in Eq. (1).

$$R_{soil} = R_{fixed}\left(\frac{V_{out}}{V_{in}-V_{out}}\right) \tag{1}$$

This formula in (1) calculates the resistance (R_{soil}) based on the output voltage (V_{out}), input voltage (V_{in}), and the fixed resistor value (R_{fixed}). The varying resistance affects the analog output voltage, which corresponds to moisture content. This signal is read by a microcontroller, which processes it to determine the precise moisture level.

When the moisture level (x%) exceeds the threshold (m%), the system initiates the drying process by activating the AC 220V components, including the thermostat and turbofan. The LED strip, connected to the thermostat, acts as a heating element, warming the air circulated by the turbofan to dry the clothes. At process initiation, power is supplied to both the turbofan and LED strip via the thermostat. The turbofan blades rotate, facilitating air intake and propulsion, ensuring continuous airflow until power is turned off.

A 10K NTC thermistor monitors the system temperature, strategically placed to detect the ambient temperature (T) around the drying area. The thermistor controls a relay that activates the LED strip when the temperature is below a maximum set point (t) and deactivates it when the temperature exceeds the maximum set point (t1), allowing it to cool down before reactivating. Users can adjust temperature limits using the up/down keys on the thermostat, tailoring the process to the fabric type, thus protecting delicate fabrics from excessive heat and maintaining their quality [19][20].

The system constantly tracks moisture levels (x%) and automatically shuts off when the moisture content falls below a preset threshold (m = 15%). This ensures energy efficiency and prevents over-drying.

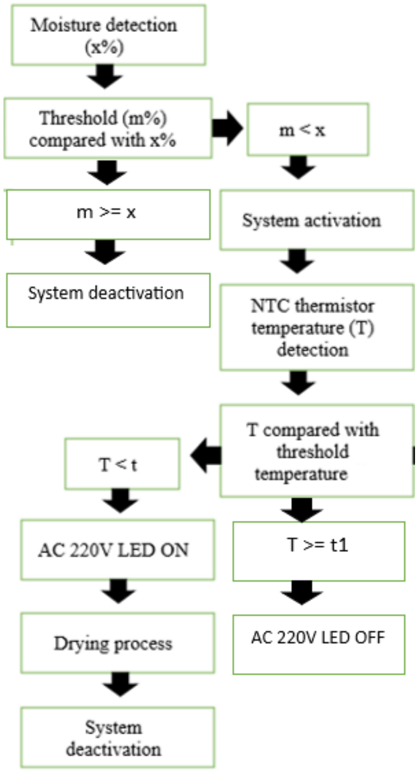

Fig. 2 Flowchart of System Operation

4. ARCHITECTURE

This section details the machine's internal and external architecture, including the pathways for warm and normal air, the configuration of plastic pipe components, the arrangement of electronic modules on a tube, and the attachments of various electronics and non-electronics hardware together.

A. Internal Architecture

The tube features strategically placed holes that direct the hot air onto the hanging clothes, as illustrated in Figure 3, which shows the position of these holes and the airflow pattern. A plastic circular strip inside the tube functions as an adjustable slider, allowing control over hot air flow to unused portions of the tube, thereby optimizing efficiency (Figure 4). The system's versatility permits installation in confined spaces due to its adjustable length. While the tube's length is fixed during manufacturing, it can be modified by cutting both the tube and the LED strip to accommodate specific home settings. This flexibility enables the system to be customized for various spatial constraints. The tube features holes on both sides, facilitating simultaneous drying of clothes from both the left and right sides (Figure 5). Hot air is driven through these holes by electronic devices that ensure consistent airflow, promoting efficient drying as the warm air circulates within the fabric sections.

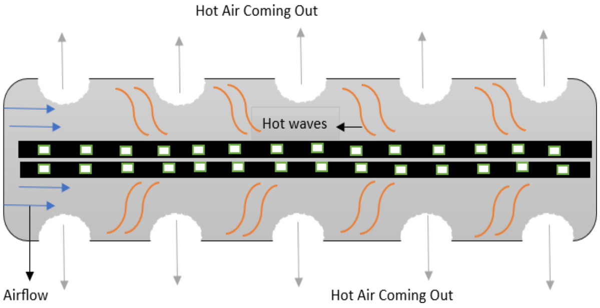

Fig. 3 Vertical cross-section area of tube (showed air pathway)

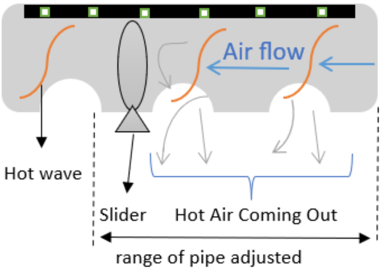

Fig. 4 Tube with Slider (side view)

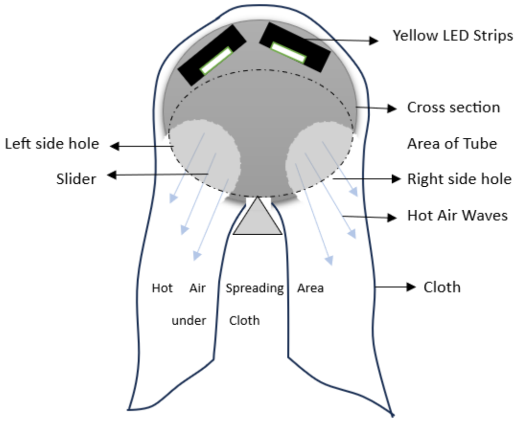

Fig. 5 Horizontal cross-section area of the tube with hung cloths.

B. *External Architecture*

This machine is designed for drying long garments, such as Indian traditional wear, which need ample space to spread out and dry effectively. The system offers two configurations: a dual-machine setup and a single-machine setup.

1) Single-machine configuration: For standard clothing that can be dried with regular warm air, the single-machine setup is adequate. In this configuration, one machine generates and circulates warm air through its tube, effectively drying normal clothing items. The single-machine setup is efficient for everyday use, providing sufficient drying without requiring dual airflow. Figure 6 illustrates the single-machine configuration for drying regular clothes.

2) Dual-machine configuration: For garments requiring extensive drying space and efficient air circulation, the dual-machine setup is utilized. In this configuration, the tube from the first machine is inserted into the tube of the second machine, enabling hot air to flow from both sides and target opposite sides of the clothes simultaneously. This dual airflow significantly reduces drying time, making it particularly effective for thick items like blankets, which require more heat and longer drying durations. Figure 7 illustrates the dual-machine configuration and its application for drying heavy fabrics.

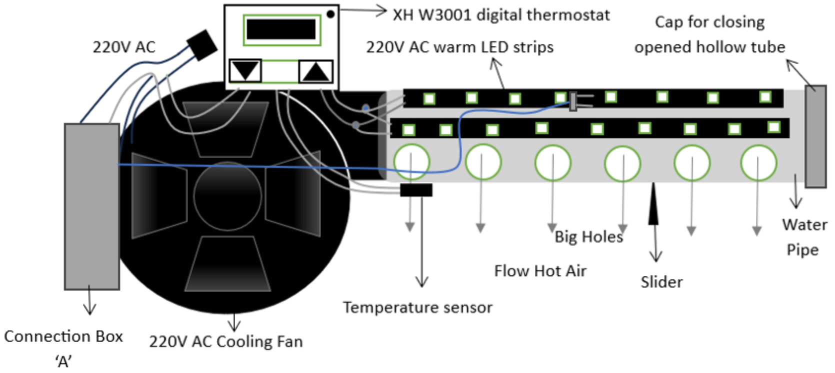

Fig. 6 Single machine configuration

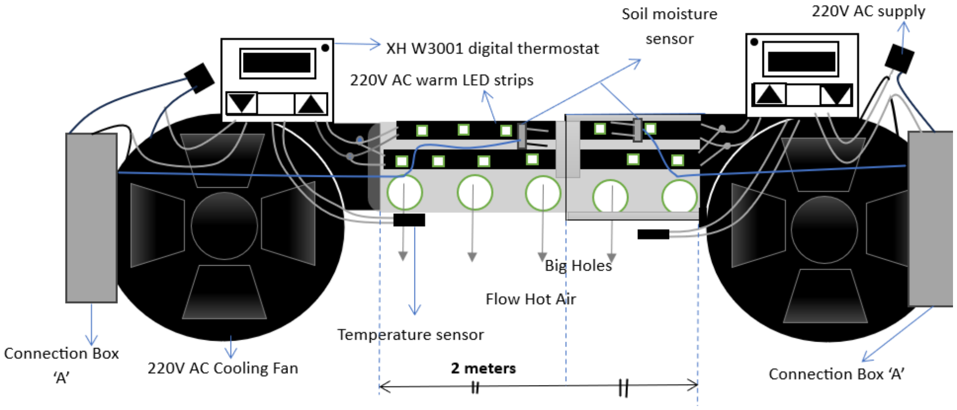

Fig. 7 Dual machine configuration

5. RESULT

Table 1 presents detailed experimental data from the testing phase of an ACDTM. This analysis involved various fabric types, where initial damp weights were recorded before commencing the drying process. The system employed a soil moisture sensor to initiate drying for fabrics with moisture content above a 15% threshold. Specifically, the drying process was activated for jeans (31%), a men's cotton singlet (40%), a cotton towel (83%), a cotton duvet (16%), and nylon Ankara (21%). However, for silk and lace blouses, with moisture readings of 8% and 7% respectively, the system remained inactive as their moisture levels were below the threshold.

In addition to moisture detection, a 10K NTC thermistor monitored the ambient heat, while a 220V AC LED strip provided supplemental warmth if the temperature fell below fabric-specific thresholds. During the testing, the LED strip was engaged for jeans, the cotton towel, and the duvet, delivering the necessary warmth for efficient drying. In contrast, the LED strip was not required for the men's singlet and nylon Ankara, as their temperatures were already above the designated threshold.

Post-drying, the fabrics were re-weighed to determine the amount of water removed, which was expressed as a percentage of the initial moisture content. The system's performance was benchmarked against natural drying times at a constant temperature of 32°C. The results showed that the drying time for jeans was reduced from 210 minutes (natural drying) to 102 minutes with the system. Similarly, the cotton towel drying time decreased from 330 minutes to 126 minutes. These findings consistently demonstrated reduced drying times, underscoring the system's enhanced efficiency and significant time-saving capabilities.

Figure 8 illustrates the practical application and ceiling installation of the machine, utilizing a ceiling plate, metal rod, and pipe holder clamp to ensure secure and proper installation on the ceiling.

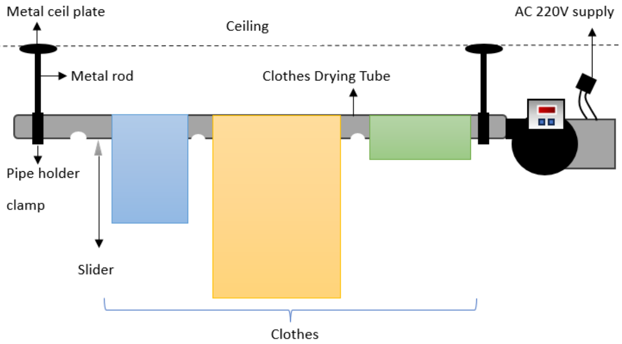

Fig. 8 Practical use of a dryer.

TABLE I. PERFORMANCE METRICS OF ACDTM

S/N	1	2	3	4	5	6	7
Fabrics	Jeans (male trouser)	Cotton (Men singlet)	Cotton (towel)	Silk (blouse)	Lace (blouse)	Cotton (duvet)	Nylon (Ankara)
Damp(gram)	735	161	1,033	148	290	2590	175
Soil moisture sensor reading (%)	31	40	83	8	7	16	21
Moist threshold comparison	15<31	15<40	15<83	15>8	15>7	15<16	15<21
System status	ON	ON	ON	OFF	OFF	ON	ON
Heat due to system (˚Celcius)	55.7	57.9	61.4	---	---	62.5	43.6
Threshold temperature comparison	62>55.7	50<57.9	68>61.4	---	---	68>62.5	42.5<43.6
AC LED strip status	ON	OFF	ON	---	---	ON	OFF
Dry(gram)	556	111	590	134	272	2199	144
Removed water mass (gram)	179	50	433	14	18	391	31
Moisture content (%)	32.19	45.05	75.08	10.44	6.61	17.78	21.52
Time required to dry by machine (minute)	102	78	126	---	---	138	36
Time required to dry naturally (minute)	210	150	330	90	75	270	150

DISCUSSION

The Automatic Cloth Drying Tube Machine (ACDTM) represents a significant advancement in fabric drying technology by incorporating sophisticated electronic components such as an AC 220V turbofan, LED strip, XH W3001 thermostat, and soil moisture sensor, all orchestrated by an Arduino Uno. This design specifically addresses the prevalent drying challenges in urban environments, where space constraints, adverse weather conditions, and high pollution levels often hinder effective drying. The ACDTM offers a compact, indoor solution that operates independently of external conditions, making it particularly suitable for urban dwellers.

Urban areas frequently face limitations in outdoor drying options due to the dense population and obstructive infrastructure. The ACDTM addresses these issues by providing a reliable indoor drying alternative. Empirical data validate the system's efficiency, demonstrating a substantial reduction in drying times. For instance, jeans, which typically require 210 minutes to dry naturally, were dried in 102 minutes using the ACDTM.

The technological integration within the ACDTM is pivotal to its performance. The soil moisture sensor ensures that the drying process is initiated only when necessary, thereby preventing over-drying and enhancing energy efficiency. The XH W3001 thermostat enables precise temperature control, allowing users to customize settings based on fabric types and thus preserving the integrity of delicate fabrics.

In terms of energy efficiency, the ACDTM leverages components such as the turbofan and LED strip to minimize energy consumption and operational costs, while also reducing environmental impact. The system's versatility is highlighted by its dual and single-machine configurations, which accommodate a variety of fabric types and household needs. This flexibility underscores the ACDTM's utility in diverse domestic settings.

Looking ahead, potential enhancements to the ACDTM could involve the integration of more advanced sensors for precise moisture detection and the implementation of machine learning algorithms to optimize drying cycles based on fabric types and environmental conditions. Additionally, exploring the use of renewable energy sources, such as solar power, for operating the ACDTM could further reduce its environmental footprint and enhance sustainability.

These advancements indicate the ACDTM's potential to significantly improve the efficiency and convenience of fabric drying in urban environments, providing a robust solution that addresses both practical and environmental concerns.

CONCLUSION

The development of the Automatic Cloth Drying Tube Machine (ACDTM) marks a substantial advancement in addressing the persistent challenges associated with efficient cloth drying, particularly in urban environments and under adverse weather conditions. By integrating an advanced electronic system that includes an AC 220V turbofan, LED strip, XH W3001 thermostat, and soil moisture sensor, the ACDTM provides a practical and effective solution to the common issue of damp clothing.

This innovative machine transcends the limitations of conventional natural drying methods, enhancing energy efficiency and user convenience through its automated mechanism. The ability of the ACDTM to detect moisture levels and adjust drying parameters accordingly ensures optimal energy consumption and safe drying operations tailored to various fabric types. Historically, traditional drying methods have faced numerous challenges, such as color fading due to sunlight exposure and inefficiency during inclement weather. The ACDTM addresses these issues by creating a controlled environment that significantly reduces drying time and ensures consistent drying quality, regardless of external conditions.

Furthermore, the compact design of the ACDTM makes it especially suitable for urban settings where space is limited, and outdoor drying is often impractical. By preventing clothes from being exposed to pollution and reducing the frequency of laundering, the machine also contributes to environmental sustainability. The review of existing literature and technologies highlights various approaches to cloth drying, each with its unique advantages and limitations. The ACDTM synthesizes these insights, offering a comprehensive solution that combines energy efficiency, ease of use, and adaptability to diverse climatic conditions. This machine stands as a testament to the potential of integrating advanced technology into everyday household appliances to improve convenience, efficiency, and environmental impact.

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