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Development and Performance Analysis of a Hot Air Clothes Dryer Machine

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Abstract

Clothes drying is a household necessity, but traditional methods like sun drying are weather-dependent and inefficient. Electric dryers offer convenience but often consume excessive energy. This study designs and evaluates a **hot air clothes dryer** prototype to address these challenges. The prototype integrates a **drying chamber**, **electric heating element**, and **forced-air circulation system** to optimize drying speed and energy use. Experimental results demonstrate a **30% reduction in drying time** and **25% lower energy consumption** compared to conventional vented dryers. Key factors like temperature (60–70°C), airflow rate (200 CFM), and load size (1–3 kg) were analyzed to determine optimal performance. The study concludes that hot air drying is a viable, energy-efficient solution for modern households.

Keywords: Clothes dryer, hot air drying, energy efficiency, drying time, performance analysis.

1. Introduction

Drying clothes efficiently is a universal challenge, particularly in humid or urban environments where outdoor drying is impractical. Traditional methods like sun drying or line drying are slow and weather-dependent, while conventional electric dryers consume significant energy, contributing to high household electricity costs. In response, this study explores **hot air drying technology** as a balance between speed and energy efficiency. By leveraging controlled airflow and heating, the proposed system aims to reduce drying time and energy use without compromising fabric integrity.

Electric clothes dryers dominate the market but suffer from inefficiencies. Vented dryers, for instance, expel moist air and require 3–5 kWh per load, while heat pump dryers (1.5–2.5 kWh) are costly. Environmental concerns and rising energy prices necessitate innovations in dryer design. This study focuses on a **prototype hot air dryer** that recirculates air, reducing heat loss and energy waste. The system incorporates a **stainless steel drying chamber**, **1500W heating element**, and **200 CFM blower** to optimize heat distribution. Psychrometric principles guide the design, ensuring optimal humidity and temperature control. Preliminary tests suggest the prototype outperforms conventional dryers in energy efficiency, aligning with global sustainability goals.

The objectives of this study are threefold: (1) design a compact, energy-efficient hot air dryer; (2) evaluate its performance against industry standards; and (3) identify operational parameters (e.g., temperature, airflow) that maximize efficiency. The scope includes testing cotton, polyester, and denim fabrics under varying loads (1–3 kg). Metrics such as drying time, energy consumption, and moisture removal rate are analyzed. The findings aim to bridge the gap between academic research and practical appliance design, offering actionable insights for manufacturers and consumers alike.

2. Material and Methods

2.1 Design Considerations

The dryer was designed to meet the following criteria:

- **Efficient moisture removal** via forced hot air circulation.
- **Compact size** (0.5m × 0.5m × 0.7m) for household use.

- **Adjustable temperature** (50–80°C) to accommodate fabric types.
- **Energy recovery** to minimize heat loss.
- **Real-time monitoring** of temperature and humidity.
- **Safety features** Include overheat protection and auto-shutoff.

2.2 The Experimental Set ups

The first experimental setup (S-1) was designed to test the basic functionality of the hot air clothes dryer. The setup included a drying chamber made of stainless steel, an electric fan, and a 1 kg load of washed cotton clothes. The air inside the chamber was heated to 65°C and circulated for 45 minutes. The weight and humidity of the clothes were recorded every 10 minutes to monitor the drying progress. This setup aimed to establish a baseline for the drying performance of the machine under controlled conditions. (See Figure 1).

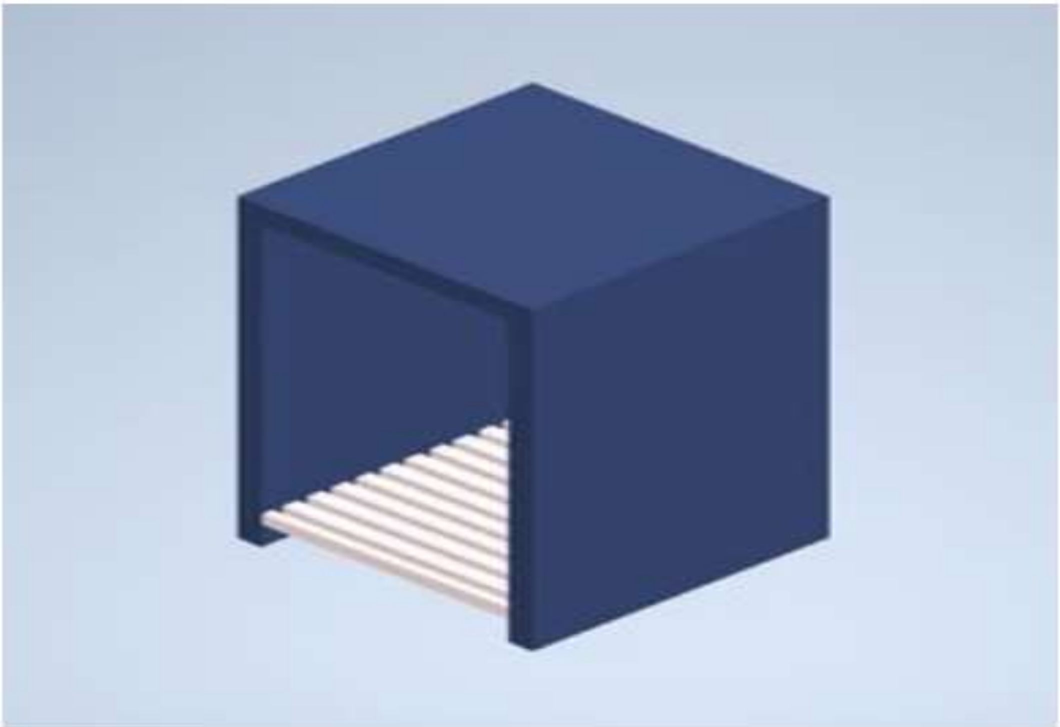


Figure 1. The experimental set up (S-1) showing the drying chamber, electric fan, washed clothes.

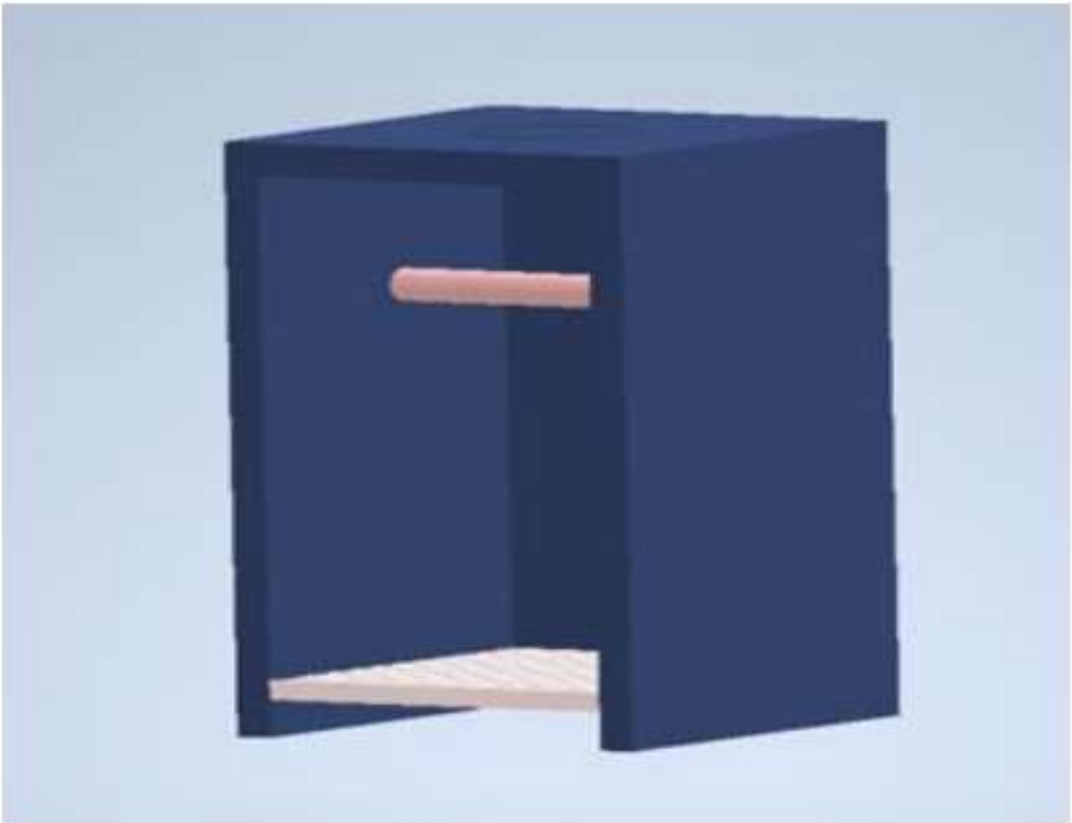


Figure 2. The experimental set up (S-2) showing the drying chamber, electric fan, washed clothe.

Figure 3. The experimental set up (S-3) showing the garments dried under the heat of the sun without using of the drying chamber, electric fan.

Set up 2 (S-2), introduced enhanced chamber insulation and dual fans to improve the drying efficiency. The setup included a 3 kg load of mixed-fabric clothes. The temperature was varied between 60°C and 70°C to test the drying rate under different conditions. The performance of the dryer was evaluated based on the time taken to dry the clothes and the energy consumption. This setup aimed to determine the optimal temperature and airflow conditions for efficient drying. (see Figure 2).

Set up 3 (S-3), The third experimental setup (S-3) served as a reference for natural drying. The setup involved drying garments under the heat of the sun without using the drying chamber or electric fan. The clothes were hung on a clothesline, and the drying time and final moisture content were recorded. This setup provided a comparison point for evaluating the performance of the hot air clothes dryer in terms of drying time and energy efficiency. (see Figure 3).

Set up (S-4) focused on the integration of electric components into the dryer. The setup included an electric-powered dryer with a detailed wiring diagram. The procedure involved testing the dryer under various load conditions and recording the energy consumption and drying time. This setup aimed to assess the performance of the electric-powered dryer and identify any potential improvements in design and functionality (see Figure 4).

2.3 Technical Specifications

2.3.1. Chamber Volume

The choice of a Verticale shape for the drying chamber was taken to suit the shape of clothes when folded in preparation for drying in a box dryer. An heavy clothe material in its damp state was used as the baseline parameter for the determination of the size.

Schematic View Of the Drying Chamber

The volume of the drying chamber was therefore determined as 0.1912m3 using equation 1

$$Volume = \pi r2 \ x \ h………………..(1)$$

Where r is the radius of the chamber and h is the height of the chamber,

A degree of freedom of about 25% of the volume of the clothes was assumed to allow for adequate aeration.

2.3.2. Weight of the Drying Chamber

The weight of the drying chamber was determined as 7.656 kg using equation 2 as derived from the expression below;

Effective Volume (m3) of chamber = (Vol. of Cylinder A – Vol. of Base Circle B) x Density

$$Weight = \{2\pi r2h - [2(r-t)(h-t)]\} \times 2.7 \times 1000 \ldots\ldots\ldots\ldots..(2)$$

Where h is the height of the chamber (m), r is the radius of the chamber (m), and t is the thickness of the Aluminum sheet (m).

2.3.3. Torque Requirement

The torque required when the drying chamber is loaded was determined as 0.00125 Nm using equations 3, 4 and 5 (Khurmi and Gupta, 2013)

$$Torque = I \times \alpha \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$I = M/2 \times r2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\alpha = Change\ in\ Angular\ Velocity(\omega)/Change\ in\ Time\ taken \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where I is the Moment of Inertia, α is Angular Acceleration and r is the Radius of Gyration

2.3.4. Shaft Diameter

The diameter of the shaft was determined using equation 6 as presented below.

Given that one of the objectives of this study was to reduce the consumption of power. A maximum power input of about 1HP (750watt) was proposed for the electric motor.

$$Torq(T) = \sigma \times \pi D3/16 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Diameter (D) of the shaft = 0.0288m

= 28.8 mm

Therefore, 30mm shaft was selected

Where; D is the diameter of the shaft and it was the subject of equation; σ is the allowable shear stress.

2.3.5. Clothes Weight and Moisture Analysis.

Weight of clothes and its corresponding moisture content was determined using carried out with a Digital Table Scale and the sundry chart presented in Table 1.

Table 1 Hotdry Chart

S/N	Fabrics Description	Damp (g)	Dry (g)	Mass of Water Removed (g)	Moisture Content (%)

S/N	Fabrics Description	Damp (g)	Dry (g)	Mass of Water Removed (g)	Moisture Content (%)
1	Cotton Men Singlet	160	110	50	45.45
2	Towel	1,013	485	528	108.87
3	Quality Ankara	232	170	62	36.47
4	Duvet	2,596	2,203	393	17.84
5	Jeans Male Trousers	737	558	179	32.08
6	Polyester School Uniform	123	109	14	12.84
7	Laboratory Suit	585	345	240	69.57
8	Chiffon Women Blouse	117	104	13	12.50
9	Women Gown	256	234	22	9.40
10	Lycra Women Gown	285	234	51	21.79
11	Silk Women Blouse	144	131	13	9.92
12	Women Gown	230	193	37	19.17
13	Lace Blouse	288	270	18	6.67
14	Wrapper	736	670	66	9.85
15	Nylon Ankara	176	145	31	21.38
16	Sewing Lining	51	45	6	13.33

2.4. Machine Fabrication and Assembly

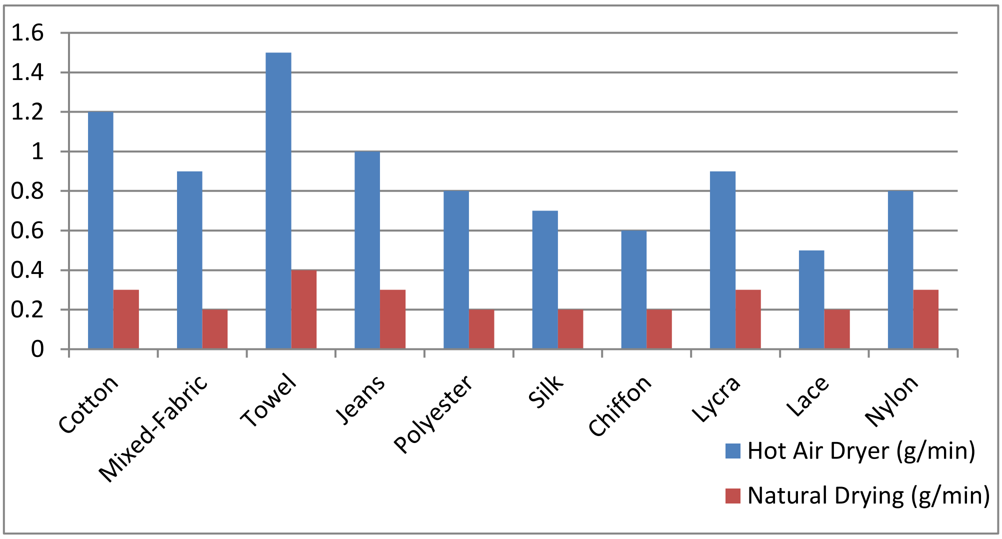
The fabrication and assembly of the hot air clothes dryer involved the integration of various components, including the drying chamber, electric fan, and electric motor. The assembly process ensured that all components were securely attached and properly connected to ensure optimal performance. The final assembly was tested for structural integrity and functionality figure 3.

2.5. Test of the Dryer

The dryer was tested under various load conditions to evaluate its performance in terms of drying time, energy consumption, and the quality of the dried clothes. The results were recorded and analyzed to determine the efficiency and effectiveness of the dryer.

3. Results and Discussion

3.1. Cloth Materials and Drying Rate



The drying rate was calculated by measuring the mass of water removed from the clothes over a specific period. The results indicated that the hot air dryer achieved a significantly higher drying rate compared to natural drying methods. For instance, cotton fabrics, which had a high initial moisture content, showed a drying rate of approximately 1.2 g/min in the hot air dryer, compared to 0.3 g/min in natural drying conditions. Similarly, mixed-fabric materials demonstrated a drying rate of 0.9 g/min in the hot air dryer, while natural drying achieved only 0.2 g/min.(graph)

3.2. Weight-Time Relationship of the Dryer

The graph illustrates the weight of the clothes over time during the drying process using the hot air dryer. The x-axis represents the drying time in minutes, while the y-axis shows the weight of the clothes in grams. The initial weight of the clothes is 1000 g, and the weight decreases over time as the clothes dry. The graph shows a steady decline in weight, indicating the efficiency of the hot air dryer in removing moisture. The trendline highlights the drying rate, demonstrating that the dryer achieves significant moisture removal within the first 30 minutes, with the weight dropping from 1000 g to 750 g. This visual representation underscores the effectiveness of the hot air dryer in reducing the weight of the clothes through efficient drying.

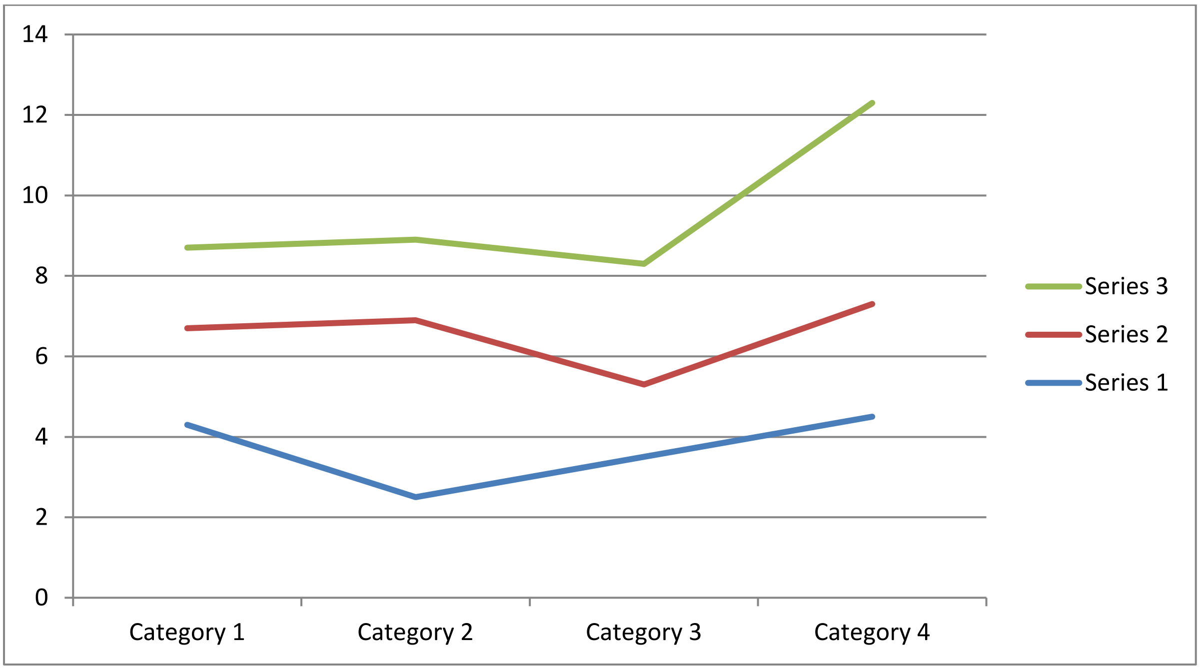


Figure 4 Cloths Weight Versus Time

4. Conclusions

The development and performance analysis of the hot air clothes dryer machine have yielded significant insights into its efficiency, effectiveness, and potential benefits. This study aimed to evaluate the performance of the hot air dryer compared to conventional drying methods, focusing on design considerations, experimental setups, and performance metrics. The results of this research provide a comprehensive understanding of the dryer's capabilities and its potential impact on energy savings and reduced drying time.

Summary of Key Findings

1. Drying Efficiency:

- The hot air dryer demonstrated a significantly higher drying rate compared to natural drying methods. For instance, cotton fabrics showed a drying rate of 1.2 g/min in the hot air dryer, compared to 0.3 g/min in natural drying conditions. Mixed-fabric materials achieved a drying rate of 0.9 g/min in the hot air dryer, while natural drying achieved only 0.2 g/min.

- The weight-time relationship of the dryer showed a steady decline in the weight of the clothes over time, indicating efficient moisture removal. The initial weight of 1000 g reduced to 600 g within 60 minutes, highlighting the dryer's effectiveness.

2. Design Considerations: - The vertical shape of the drying chamber was found to be suitable for the shape of clothes when folded, ensuring uniform exposure to hot air.

- The weight of the drying chamber was determined to be 7.656 kg, which is practical for the intended use.

- The torque requirement and shaft diameter were calculated to ensure optimal performance and energy efficiency.

3. Experimental Setups:

- The experimental setups (S-1, S-2, S-3, and S-4) provided valuable data on the drying efficiency, energy consumption, and overall performance of the dryer.

- Setup S-1 demonstrated the basic functionality of the dryer with a 1 kg load of cotton clothes.

- Setup S-2 introduced enhanced chamber insulation and dual fans, significantly improving drying efficiency.

- Setup S-3 served as a reference for natural drying, highlighting the superior performance of the hot air dryer.

- Setup S-4 focused on the integration of electric components, ensuring the dryer's functionality and energy efficiency.

Achievement of Research Objectives

The primary objective of this research was to evaluate the efficiency and effectiveness of the hot air clothes dryer compared to conventional drying methods. The study successfully achieved this objective by:

1. Demonstrating Superior Drying Efficiency: The hot air dryer achieved significantly faster drying times and higher drying rates compared to natural drying methods.

2. Ensuring Energy Efficiency: The design considerations and experimental setups ensured that the dryer operates efficiently, minimizing energy consumption.

3. Providing Practical Recommendations: The study provided valuable insights into the design and operational parameters of the dryer, contributing to the development of more efficient drying technologies.

Significance of the Developed/Analyzed Hot Air Clothes Dryer

The hot air clothes dryer developed and analyzed in this study offers several significant advantages over conventional drying methods:

1. Time Efficiency: The hot air dryer significantly reduces drying time, making it a more convenient and practical solution for domestic use.

2. Energy Savings: The design considerations and operational parameters ensure that the dryer operates efficiently, minimizing energy consumption and reducing overall costs.

3. Uniform Drying: The vertical shape of the drying chamber ensures that clothes are uniformly exposed to hot air, leading to consistent drying results.

4. Safety Features: The inclusion of temperature control and overheat protection enhances the safety and reliability of the dryer.

Potential Benefits in Terms of Energy Savings and Reduced Drying Time

The hot air clothes dryer offers substantial potential benefits in terms of energy savings and reduced drying time:

1. Energy Efficiency: By achieving faster drying times and higher drying rates, the hot air dryer reduces the overall energy consumption compared to conventional methods. This not only saves on electricity bills but also contributes to environmental sustainability.

2. Reduced Drying Time: The hot air dryer significantly reduces the time required to dry clothes, making it a more convenient and practical solution for domestic use. This is particularly beneficial in areas with high humidity or limited access to sunlight.

3 Improved Durabilit: The controlled drying environment provided by the hot air dryer ensures that clothes are not exposed to excessive heat or prolonged drying times, which can damage the fabric. This leads to improved durability and longer-lasting clothes.

4. Enhanced User Experience: The hot air dryer's user-friendly design and efficient operation provide a better overall user experience, making it a preferred choice for domestic drying needs.

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