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SmartDryBox: An Eco-Friendly Automatic Clothes Dryer Based on Air Conditioner Waste Heat and IoT

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Abstract
Smartdrybox represents an innovative clothing dryer designed to mitigate electrical energy consumption and carbon emissions by harnessing waste heat from air conditioning (AC) systems. Grounded in the 6R framework (Reuse, Reduce, Rethink, Recycle, Repair, and Replace), this system integrates an Internet of Things (IoT) mobile application to facilitate real-time drying monitoring. The primary objective of this development is to present an energy-efficient solution tailored for residential households, boarding houses, and micro-scale laundry enterprises, thereby decreasing reliance on conventional electric dryers. Structurally, the Smartdrybox consists of a cabinet drying enclosure coupled to the AC exhaust outlet via an adjustable duct system. A built-in humidity sensor quantifies the moisture level of the garments, while a diffuser ensures uniform airflow distribution. An integrated microcontroller processes the acquired sensor data and transmits telemetry to the user through a dedicated IoT application. Furthermore, automated notifications are generated upon completion of the drying cycle, with drying durations fully adjustable to meet specific operational requirements. This innovation yields several distinct advantages, including the valorization of AC thermal waste (Reuse), the integration of IoT to optimize temporal efficiency, and a modular design compatible with diverse air conditioning configurations. Additionally, the system ensures fabric preservation across various textile types due to the absence of auxiliary heating elements. By synthesizing the 6R principles, IoT-driven automation, and energy recycling, the Smartdrybox aligns with green technology and smart home paradigms, demonstrating substantial potential for future research and development.

1. Introduction

In daily life, clothing dryers are essential, particularly in high-humidity environments and during prolonged rainy seasons. However, conventional electric dryers present several disadvantages, including high energy consumption, substantial operational costs, and elevated carbon emissions. Conversely, the thermal waste generated by air conditioning (AC) systems is frequently dissipated without utilization, despite its potential as a more environmentally friendly alternative energy source (Dai et al., 2020; Hanif et al., 2019). The 6R framework—comprising Reuse, Reduce, Rethink, Recycle, Repair, and Replace—drives innovation toward optimizing the efficiency of waste or unutilized resource exploitation. A pertinent application is the use of AC exhaust air for garment drying. This method not only mitigates energy wastage but also reinforces the paradigms of green technology and sustainability (Tokar et al., 2019; Wang et al., 2020). Furthermore, the emergence of the Internet of Things (IoT) enables the integration of automated systems to monitor and regulate the drying process in real-time, thereby enhancing operational efficiency and user convenience (Wang et al., 2020; Naemsai et al., 2019). Consequently, the Smartdrybox is introduced as an innovative solution that synthesizes IoT technology with the utilization of AC thermal waste. This apparatus is designed to reduce reliance on conventional electric dryers, optimize energy efficiency, and facilitate user operation via smartphone-based telemetry monitoring. The Smartdrybox not only curtails energy expenses but also yields socio-economic benefits for residential households, boarding houses, and micro-scale laundry enterprises. The development of the Smartdrybox aligns with global initiatives to mitigate carbon emissions and foster sustainable smart technologies. It is anticipated that this innovation will contribute significantly to the advancement of future green technology and smart home ecosystems..

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2. Method

An experimental methodology was employed in this study to evaluate the performance of the Smartdrybox by utilizing AC thermal waste as an energy source. This method was selected because it enables direct observation of system performance, precise measurement of humidity parameters, and rigorous analysis of energy efficiency.

2.1. Implementation Procedure:

1. System Design

- The Smartdrybox was developed as a modular drying enclosure connected to the air conditioning (AC) exhaust outlet via a flexible duct system.
- A humidity sensor (DHT22) was integrated into the enclosure to monitor garment moisture levels.
- An ESP8266 microcontroller was utilized to process the sensor telemetry and transmit data to a smartphone interface using an IoT-based platform (e.g., Blynk or Thinger.io).

2. Performance Testing

- Garments under standardized wet conditions (with controlled weight and fabric types) were introduced into the Smartdrybox.
- AC thermal waste was directed into the enclosure, and the drying progression was monitored in real-time.
- Key parameters, including humidity, temperature, and drying duration, were recorded to facilitate energy efficiency analysis.

2.2. Materials and Instrumentation

1. An aluminum-based drying enclosure.
2. An adjustable duct system and a diffuser for uniform airflow distribution.
3. A DHT22 humidity sensor, an ESP8266 microcontroller for IoT integration, and a relay module.
4. A 1-HP (Horsepower) split-type air conditioning unit serving as the thermal waste source.
5. An IoT-based application platform (e.g., Blynk or Thinger.io) utilized for real-time monitoring telemetry.

3. Result and Discussion

The following section presents the experimental results derived from the prototype evaluation of the SmartDryBox, conducted to assess system performance across diverse operational dimensions. This evaluation encompasses several critical parameters, including thermal performance, drying efficiency, temperature and humidity stability within the drying enclosure, energy consumption, and the functionality of each supporting component. The empirical data obtained from these tests serve to evaluate the effectiveness, reliability, and feasibility of the prototype in optimizing the garment drying process under various operational conditions.

a. Thermal Efficiency of AC Exhaust Air

- The temperature of the AC exhaust air prior to entering the drying enclosure ranged between 40°C and 45°C.

- Following diffusion, the internal temperature of the drying enclosure stabilized at 35°C to 38°C, indicating a thermal loss of approximately 5°C due to insulation factors.

- The thermal output remained stable for 2 to 3 hours post-activation of the air conditioning unit, which is sufficient for drying lightweight garments.

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b. Drying Duration for Various Fabric Types

The drying duration required for various fabric types is presented in Table 1.

Figure 1. Smartdrybox design

Table 1. Drying Time of Different Fabric Types

Fabric Type	Initial Moisture Content (%)	Final Moisture Content (%)	Drying Time (min)
Cotton	80	15	90
Wool	75	20	120
Synthetic	70	10	60

Table 2. Comparison Between SmartDryBox and Conventional Electric Dryers

Aspect	SmartDryBox	Conventional Electric Dryer
Energy Source	Waste heat from air conditioner exhaust (0 W additional power)	Electricity (1000–3000 W)
Carbon Emissions	0 kg CO_2	0.5 kg CO_2/h
Operating Cost	Low	High
Drying Control	Automatic (IoT-based)	Manual/Timer

c. Sensor Accuracy and IoT Responsiveness

- The DHT22 sensor detects humidity fluctuations with an accuracy margin of 2%.
- Smartphone notifications (via the Blynk platform) are transmitted within a latency threshold of <5 seconds once the relative humidity drops below 20%.

d. Energy Efficiency and Carbon Mitigation

- In comparison to conventional electric dryers, which consume between 1000 and 3000W, the Smartdrybox utilizes pre-existing operational air conditioning thermal output, requiring 0 W of auxiliary power (Lamidi et al., 2019).
- Carbon emission calculation:
  - Conventional electric dryer (1 hour of operation) = 0.5kg CO_2
  - Smartdrybox = 0 kg CO_2 (by virtue of reclaiming thermal waste).

3.1. Discussion

Eco-friendly technological innovation has now arrived in the form of Smartdrybox, a smart clothes drying device efficiently designed to harness the waste heat potential from air conditioning (AC) systems. In its operation, this device captures the hot air emitted from the outdoor unit and directs it straight into the drying chamber, allowing the drying process to run optimally without requiring additional electrical energy or extra operational costs. This approach not only offers a practical solution for modern household needs, but also effectively eliminates thermal energy waste by transforming environmental waste heat into a productive, energy-efficient resource that supports environmental sustainability.s (Dabizha et al., 2019; Ismaeel & Yumrutaş, 2020). This method not only optimizes existing energy utilization but also eliminates the need for traditional dryers that require auxiliary electricity, thereby yielding significant financial savings and reducing household electrical loads (Anastasovski, 2019). By leveraging this wasted energy source, the Smartdrybox establishes a more environmentally friendly and sustainable drying system without compromising performance or user convenience. Consequently, this system presents an ideal solution for tropical environments characterized by high air conditioning usage (Dabizha et al., 2019; Raitila & Tsupari, 2019; Dolgun et al., 2020).

By substituting conventional electric dryers with an innovative approach, the Smartdrybox mitigates carbon emissions (Pranasyahputra et al., 2020). This approach aligns fully with the 6R framework, specifically emphasizing the Reuse dimension. AC exhaust air, which previously constituted unutilized thermal waste, is now reclaimed as the primary energy source for the drying process. This simultaneously achieves two critical objectives: first, it reduces the demand for conventional dryers, which account for 5% to 10% of household energy consumption and generate 0.5 to 1 kg of CO2 per operational hour; second, it implements circular economy principles by optimizing the utilization of AC thermal waste to maximize its utility (Admaja et al., 2020; Nugraha et al., 2020). This reuse principle not only yields a one-hundred-percent reduction in carbon emissions during the drying process but also establishes a new paradigm for energy waste utilization within households. Every system component is designed to maximize the utility of existing resources without imposing additional environmental burdens. Consequently, the Smartdrybox serves as a concrete manifestation of how the 6R philosophy can synthesize straightforward technology with sustainable solutions to address modern environmental challenges (Multazam & Zulfadli, 2020).

The Smartdrybox exhibits substantial potential for both business expansion and technological advancement. Given its energy efficiency and minimal operational costs, this product is highly suited for small-scale commercial applications, such as laundry enterprises and boarding houses (Li et al., 2020; Cranston et al., 2019). To enhance system autonomy, subsequent developments could integrate photovoltaic panels as an auxiliary energy source. This integration would decrease reliance on the grid-supplied AC electrical system and bolster its overall sustainability (Tiwari et al., 2020). Furthermore, smart home features—such as compatibility with voice-controlled assistants like Google Assistant or Alexa—would align the product with contemporary smart home trends, allowing users to regulate the drying process via voice commands. This innovation would not only broaden market viability and elevate product utility but also position the Smartdrybox as an intelligent, efficient, and ecologically responsible garment-drying solution in the modern era (Khan et al., 2020).

4. Conclusion

The experimental evaluation and subsequent analysis demonstrate that the SmartDryBox, which utilizes waste heat from air conditioner exhaust integrated with IoT technology, represents an innovative and environmentally sustainable solution for garment drying. Compared with conventional electric dryers, the system significantly reduces electrical energy consumption by reclaiming waste thermal energy that would otherwise be dissipated. Furthermore, by applying the **Reuse** principle within the 6R framework, the SmartDryBox promotes energy conservation and reduces carbon emissions, thereby supporting green technology initiatives. The prototype successfully dried various fabric types within 60 to 120 minutes while maintaining reliable performance, and the integration of sensors with IoT technology enabled real-time monitoring through a dedicated mobile application, enhancing operational accuracy and user convenience. In addition, the SmartDryBox offers a cost-effective drying solution for households, boarding houses, and small-scale laundry businesses, while raising public awareness of waste energy utilization. Overall, the SmartDryBox demonstrates strong potential as an efficient, sustainable, and economically viable garment-drying system that contributes to the advancement of green technology and energy independence. Nevertheless, further research is recommended to optimize system performance, improve scalability, and expand its applicability across broader environmental and operational conditions.

Author Contributions

All authors have equal contributionsto the paper. All the authors have read and approved the final manuscript.

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