ECOSIA | International Conference
Institut Teknologi dan Bisnis Asia Malang
Indonesia, 10 December 2025

A Study of Energy Efficiency And Thermal Performance of A Smart Shoe Drying System In Supporting Green Technology Applications

Nur Rafiqah Rosly[1]
Siti Khalijah Shuib[1]
Mohamad Shahril Ibrahim[2]
Noor Mayafaraniza Kosnan[1]

[1]Affiliation: Politeknik Melaka, Malaysia
[2]Affiliation: Politeknik Kuching Sarawak, Malaysia
Correspondence E-mail : nurrafiqah@polimelaka.edu.my

Abstract

Introduction/Main Objectives: The purpose of this study is to understand the energy efficiency and thermal characteristics of using Positive Temperature Coefficient (PTC) heaters in a smart shoe drying system, to support the development of sustainable and energy-efficient Green Technology innovations.

Background Problems: Current shoe-drying methods are inefficient and problematic. Air-drying is slow, while using hair dryers or heaters wastes energy and risks damage due to overheating and lack of temperature control. While a new smart dryer with a PTC heater has been designed to solve this, its actual energy efficiency and thermal performance remain unstudied. Without examining its electricity use, how shoe type affects drying, and how well it converts energy to evaporate moisture, it's unclear if this system is truly an effective and sustainable green technology.

Research Methods: The smart shoe drying system was tested using three shoe types (sports shoes, casual shoes, and safety boots) at a controlled operating temperature of 45°C (±0.5°C) with a 240V AC power supply. Drying time was measured with a digital stopwatch, energy consumption with a multi-meter, and water mass by weighing the shoes before and after wetting.

Finding/Results: Sports shoes dried the fastest (24 minutes) and had the highest energy efficiency at 50.2%. Safety boots and casual shoes showed lower efficiencies of 33.7% and 29.7%, respectively. Energy consumption per drying cycle ranged from 0.874 to 1.674 kWh, classifying the system below the moderate consumption range. The PTC heater's self-limiting temperature feature ensured stable operation without additional thermal controls, minimizing overheating risks and energy loss. The 3D-printed drying chamber effectively promoted rapid evaporation and maintained safety.

Conclusion: This smart shoe drying system qualifies as a small-scale green electrical appliance with significant potential. Future upgrades integrating solar energy and IoT optimization could position it as a class A+ energy-saving device within domestic sustainable development frameworks.

Keywords: Green Technology, PTC Heater, Energy Efficiency, Thermal Performance, Smart Shoe Dryer, Renewable Energy, IoT Automation System

Introduction

Digital technology advancements and growth of e-commerce have impacted consumer behavior in a number of ways. Wearing wet shoes during rain, exercising, or when working in a wet environment can lead to problems with bacteria, mildew, and even bad smells. Traditional methods of shoe-drying such as sun-drying, use of a fan, or hair-dryers are ineffective, and can either damage the shoe, use excess electricity, or take a long time. In today's society, consumers are looking for shoe-drying methods that are quicker, safer, and use less energy. One of the most popular electrical heating technologies for this purpose is Positive Temperature Coefficient (PTC) heaters. They have the ability to self-regulate as the temperature rises and so does the resistance, leading to a decrease in the current. This selfregulating ability makes PTC safer and more efficient than conventional heating elements. Thus, a system that incorporates a PTC heater, a fan module, and a 3D-printed enclosure chamber for the purposes of shoe-drying, was created. In the initial report, the focus was on the main aspect of product development. This is the reason this report was conducted, to focus on energy efficiency and thermal scientific data and the effective use of a tested system for three kinds of shoes, sports shoes, casual shoes, and safety boots.

Current methods for drying shoes are less than ideal for a number of reasons. First, relying on the sun takes hours for the shoes to dry. Second, using a hairdryer or space heater takes a lot of power and there is the danger of overheating shoes and damaging the materials. Third, there is no definite way to set a particular temperature or range to prevent shoes from being damaged from too much over the modern athletic shoes. A smart shoe-drying system has been designed with a PTC heater, but to my knowledge, there has been no systematic investigation of its energy efficiency and thermal performance. This brings to mind a number of questions: how much electrical energy is actually used in each drying cycle? How does the type of shoes being dried and the energy used, if at all, affect the drying period? And how much is the energy of the PTC heater actually used to vapors liquid vs. that energy being used to heat surrounding air? Without a systematic investigation, it is virtually impossible to determine whether this system is efficient in its use of electrical energy and represents a device that should be classified as a consumer item embodying energy-efficient and ecologically sustainable technology. Thus, the purpose of this work is to measure and analyze how effective the system is and how the system works thermally.

The specific objectives of this study are:

1. To determine the thermal characteristics of the smart shoe drying system by measuring the mass of the shoes before and after wetting, the operating temperature, and the drying time for three different types of shoes.
2. To analyse the energy efficiency of the PTC heater, including the electrical energy consumed and the ratio between moisture evaporation energy and input electrical energy.
3. To compare the thermal performance of the system according to shoe type, to identify the most efficient combination of shoe type and operating conditions from the perspective of drying time and energy consumption.

The parameters of this study are confined to the design of a smart shoe dryer using a PTC Heater while powered with a 240 V AC supply at 13 A with a total power of 3120 W. The power of the system gets recalculated to 2184 W after estimating the heat loss to be 30 %. The system was tested with a sample of 3 shoes each of: sports shoes, a casual shoe, and safety boots. The test runs are done at a threshold of 45 degrees Celsius which is confirmed to be a temperature range safe for the shoes composition and primary materials used. The main parameters of the experiment included: total shoe mass before and after the drying process, mass of the water to be evaporated, total time required to dry the shoes at the stated temperature, and total energy consumption. The experiment did not account for the smell, the subjective comfort of the user, antibacterial properties from the humidifier, and overall design of a smart shoe dryer.

Dryers and certain types of footwear dryers use nichrome coils, which is a standard form of heating element, to generate heat. However, it has been proven that this method is inefficient and unsafe due to poor temperature control and high energy consumption (D.D. Prasanna Rani et. al., 2023). Given the demand for green technology, recent studies have introduced Positive Temperature Coefficient (PTC) ceramic heaters that are self-limiting. When the temperature rises, the electrical resistance rises, and the current is limited, making energy use safer and more efficient (Mani et. al., 2025).

Yufei Wang et al. (2024) studies have shown that with the use of a PTC heater in an air dryer system, the operational temperature can be maintained with a control band of only ±2°C, in contrast to a ±7°C band with conventional heaters. Thus, there is an advantage in thermal efficiency with energy savings to the order of 15%. In addition, Imam Hossain et. al. (2022) reported that a mini dryer system with PTC use and directed airflow can reduce the fabric drying time by 30% with an energy consumption of 20% less.

In the small-scale application aspect, smart appliances PTC heaters have been widely used in such as space heaters, hair dryers, and footwear dryers due to their compact, safe designs, and no need for complex electronic controls (Maryam Alghfeli, 2022). Studies of Muharemovic et al. (2021) pula illustrates that the efficiency of shoe dryer systems can be improved by controlling the operation time and designing the internal ventilation ducts to ensure even airflow, which helps to quicken evaporation of water from the textiles.

When it comes to green technology, energy efficiency becomes the most important indicator in the design and development of contemporary electrical products. Hussain et al. (2024) claim that the use of high-efficient devices leads to a decrease in carbon emissions by 25–30% during the entire lifecycle of the device. Moreover, SEDA Malaysia (2023) states that energy monitoring of small devices, such as dryer systems, can help achieve the Low Carbon Appliance Initiative as part of the National Green Technology Policy 2030.

Overall, the literature demonstrates that PTC heaters hold great prospects for application in shoe dryer systems that offer greater safety, efficiency and alignment to the green technological agenda. However, empirical analysis of the relationship between temperature, drying time, and electrical energy consumption for various types of footwear is still lacking (Bokolo Anthony, 2019). Therefore, the present study aims to examine the energy efficiency and thermal performance of a smart shoe dryer system, PTC heater technology applied to sustainable green engineering.

Research Methods

This study uses a quantitative experimental approach to evaluate the energy efficiency and thermal performance of a smart shoe drying system. The study was conducted in an engineering laboratory using a repeated measures design involving three types of shoes sports shoes, casual shoes, and safety boots under a fixed operating temperature of 45°C. A PTC heater was used as the main heating element with time control and a 240V AC power supply. The experimental design was planned to measure three main dependent variables:

1. Drying time (minutes)
2. Electrical energy used (kWh)
3. Energy efficiency (%)

While the independent variables were the type of shoe and the mass of water absorbed (kg). All data were obtained through actual measurements based on repeated tests (n = 3 for each shoe type) to ensure data reliability.

Table 1 Equipment and Main Components

Component	Specification / Function
PTC Heater	Nominal power 3120 W (240 V AC, 13 A), ceramic material
Digital temperature sensor	Measures drying chamber temperature (0.5°C accuracy)
Digital weighing scale	Measures shoe mass before and after drying (0.1 kg accuracy)
Infrared thermometer	Monitors the stability of the chamber surface temperature
Digital stopwatch	Records actual drying time
Digital Voltmeter & Ammeter	Measures actual voltage and current for electrical energy calculation
3D printed drying chamber	Closed design to reduce heat loss
Mini DC fan	Circulates hot air uniformly inside the drying chamber

Source : Research Data, 2025

Experimental Procedure

1. Getting Your Shoes and System Ready
   Three different but similar-sized shoes were chosen. Each pair was dipped in fresh water for 2 minutes, achieving fully saturation, allowed to drip for 2 minutes, and then weighed (wet mass,m_b)
2. Getting the Mass of The Water That Was Absorbed
   The mass of shoes was recorded after fully drying them in an oven at 60° C for 4 hours. Mass of absorbed water was calculated with this equation:
   $$m_{air} = m_b - m_k$$
3. The Drying Process
   The shoes were then positioned in the custom-made, 3D-printed drying chamber, which contains both a PTC heater and a fan. The heater turned on to 45ºC, and the drying timer started once the chamber temperature stabilized. To ensure stable thermal conditions, temperature measurements were recorded in 5-minute intervals.
4. Electrical Energy Calculation
   Using a digital multimeter, the actual power (P) was determined. The input electrical energy value was then calculated using the following equation.
   $$E_{elek} = P\ x\ t$$
   where t is the drying time (hours) and E_{elek} in kWh units.

5. Water Evaporation Energy
   The thermal energy required to evaporate the water is calculated based on the mass of absorbed water (m_{air}) and the latent heat of water vaporisation (L_v=2.26×10^6 J/kg)

$$E_{wap} = m_{air} \, x \, L_v$$

6. Energy Efficiency
   The energy efficiency (□) of the system is determined by the ratio of water evaporation energy to input electrical energy:

$$□ = \frac{E_{wap}}{E_{elek}} \, x \, 100\%$$

7. Repeating Tests and Recording Data:
   In order to be able to validate the results, each shoe was tested more than three times. Average values were recorded for the water mass, time, electrical energy, and efficiency for the final evaluation.

Data Analysis Method

1. Descriptive Analysis:
   Using means and deviations of standards, raw data were analyzed.
2. Comparison of Shoe Types:
   Shoes were compared using graphs showing the relationship between water mass and time spent and energy used to dry.
3. Energy Efficiency Comparison:
   Among the three types of shoes, energy efficiency values were compared to find the best effective pair of shoes.
4. Thermal Analysis:
   The temperature of the drying chamber was charted to assess the stability of the PTC heater during the drying process.
5. Discussion of Green Technology: domestic standard (<1.5 kWh for 1-hour operation) energy efficiency was used to analyse the results

Result

The Validity and Reliability of the Data Internal validity was the most important component in this analysis and was achieved by balancing the measuring instruments before the experiment: scales, thermometers, and multimeters. To augment external validity, the study utilized three types of shoes reflecting actual customer segments in the market. All information was documented in digital data sheets and thoroughly verified prior to the analysis.

Basic Data and Initial Observations

Tests were conducted using three different types of shoes to evaluate the effect of structure and material on drying time and efficiency. Readings of mass before and after wetting, absorbed water mass, and drying time at a temperature of 45°C were recorded as follows:

Table 2 Basic Data of Shoe Drying Tests

Shoe Type	Dry Mass (kg)	Wet Mass (kg)	Absorbed Water Mass (kg)	Drying Time (minutes)	Average Chamber Temperature (°C)
Sports shoes	0.7	1.4	0.7	24	45.1
Casual shoes	1.2	1.7	0.5	29	44.9
Safety boots	1.8	2.7	0.9	46	45.0"

Source : Researched Data, 2025

In the beginning, the first conclusions were made where the safety boots, due to highest material thickness and additional inner layers, held the highest moisture, resulting in 46 minutes of the longest drying duration. On the other hand, sports shoes required 24 minutes because of the mesh and light weight fabric, which allowed for more air flow and circulation to evaporate moist air.

Energy and Efficiency Analysis of the PTC Heater

The actual electrical energy used per session was calculated based on the effective haul of the heater (2184 Watts) and the duration of drying. The energy value absorbed at water evaporation was calculated based on the mass of water. The difference between the two gives the value system energy efficiency as in table 3 below.

Table 3 Analysis of Electrical Energy and Efficiency of the PTC Heater

Shoe Type	Time (minutes)	Electrical Energy Used (kWh)	Water Evaporation Energy (kJ)	Energy Efficiency (%)	Energy per kg Water (Wh/kg
Sports shoes	24	0.874	1,579.2	50.2	1,248.0
Casual shoes	29	1.056	1,128.0	29.7	2,111.2
Safety boots	46	1.674	2,030.4	33.7	1,860.4

Source : Researched Data, 2025

The Relationship Between Water Mass and Drying Time

There is a moderate positive correlation (r=0.72) between water mass absorbed and the drying time. This means that water mass can increase and drying time would not increase in a linear fashion, and varying fabric design, porosity, and air distribution could also play a part. Sports shoes water mass of 0.7 kg dried faster than casual shoes, which only absorbed 0.5 kg of water, showing how effective the internal ventilation design is.

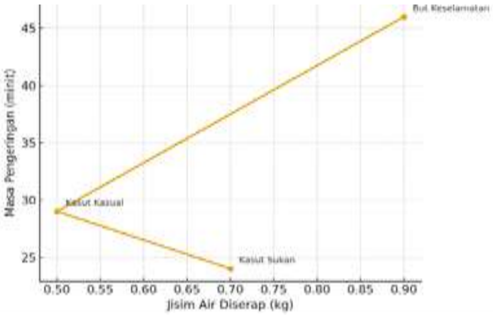

Figure 1 Relationship of Water Mass vs. Drying Time
Source : Researched Data, 2025

(A simple ascending line graph, showing three data points of sports, casual, safety at a given time increasing based on water mass)

Relationship between Drying Time and Energy Efficiency

The relationship between drying time and energy efficiency is negatively correlated (r=0.81), as higher drying time leads to a lower energy efficiency. This happens because some of the thermal energy is dissipated to the chamber wall of the dryer and to the surrounding air when the operation time exceeds to be too long.

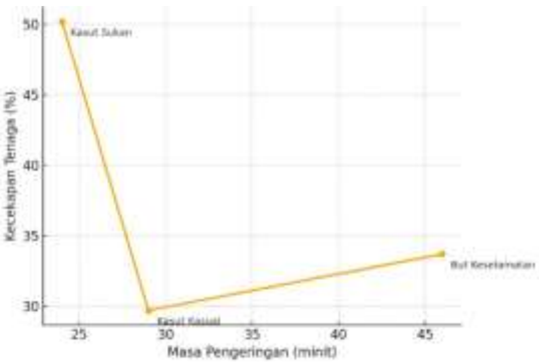

Figure 2 Relationship of Drying Time vs. Energy Efficiency
Source : Researched Data, 2025

(A descending line graph, showing that sports shoes achieved the highest efficiency around 50%, followed by safety boots 33.7%, and casual shoes 29.7%))

Discussion

The type of material and construction of the shoes fit the design and construction of the system and determine the energy efficiency of the system. Sports shoes, as being made of porous mesh fabric, are able to facilitate the flow of hot air and lower the resistance to the evaporation of water. Hence, this is where the highest efficiency (50.2%) and the lower energy per unit of water (1,248 Wh/kg.) are achieved. Meanwhile, the casual shoes, employing a synthetic material that is a laminate, draw a zone of uneven heat as a result of heat being expended to evenly raise the materials of the laminate and the air volume of the chamber. The mass of the water is small (0.5 kg) which, even so, gives rise to a much higher energy to heat the zone diverted to that laminate. With the safety boots, there is an advantage that they have wellengineered heat retention due to a thick rubber structure. Certainly, there is an air flow retention, the drying time is relatively long (46 min.) and the efficiency is moderate (33.7 %). The main advantage of the PTC heating system is well demonstrated due to the consistency of the operating temperature remaining stable (around 45 °C ± 0.5 °C) throughout the test."

This further confirms the independently regulating temperature attribute, making the system safer and increasing energy savings. The overall mean system energy efficiency is 37.9%. The energy spent electrically, per module used, is from 0.874 to 1.674 kWh.

From the green technology standpoint, the system can still be placed as a moderately efficient appliance as the energy consumption is still below 2 kWh/hour, which is in the range of the Malaysian domestic appliance. The green appliance system can be further improved with the addition of automatic temperature control and other energy sources (e.g. solar DC). This is achievable as per the Malaysian standards SEDA (2023) which classifies such a system as Green Appliance Class A+.

Summary of Findings

Athletics shoes performed the best in terms of time and energy efficiency, at 24 minutes and 50.2% efficiency.

1. Casual shoes had the lowest efficiency due to the less porous material design.
2. Safety boots had high water retention, but heat retention as well.
3. The system can be used as a small-scale green energy appliance as it achieved an average heat retention of 45°C with minimum heat loss.

Conclusion

In this regard, this study has achieved its actual purpose, which is to determine the energy efficiency and thermal performance of a smart shoe drying system with a PTC heater, as an attempt to aid the green technology applications.

Several important conclusions can be summarized from experimental data conducted on three types of shoes: sports shoes, casual shoes, and safety shoes.

1. The type of shoe determines the system's energy efficiency.
   With a thermal and energy efficiency of 50.2%, sports shoes had the best thermal and energy efficiency. Casual shoes had the lowest thermal and energy efficiency of 29.7%, which was due to the thermal material structure of the shoe which was less porous to air. Safety boots had a moderate efficiency of 33.7%, albeit of a greater heat retention capacity.

2. The structure of the material and the design of the shoes influenced the drying time. Absorbed water mass did not linearly increase the drying time due to differing material construction, and air permeability of the shoes, with shoes designed with porous mesh fabric drying in a maximal 24 minutes at 45°C.

3. The PTC heater functions with high temperature stability, safety, and reliability. The heating system equilibrated around 45 °C ± 0.5 °C which exemplifies the PTC set characteristic of self-regulation of temperature for stability and safety with a loss risk of fire.

4. The system is categorized as a moderately energy-efficient system and from a green technology perspective, has energy consumptions of 0.874 to 1.674 kWh of energy per session. This is also below the 2 kWh/hour mark dictated by Malaysian domestic energy standards (SEDA Malaysia, 2023).

5. This research confirms the positive impact of the closed chamber design with simultaneous temperature regulation mechanisms in reducing thermal energy loss. This also helps advance small-scale drying system innovations in Green Campus initiatives and Sustainable Consumer Appliance Development in polytechnic institutions.

All in all, the smart shoe drying system that employs a PTC heater not only caters to the need to dry safely and quickly, it demonstrates substantial promise within the domestic green energy appliances segment. The research demonstrates that the fusion of a PTC heater, 3D printed drying chamber, and temperature constant design, in the context of engineering design approach, achieves better energy performance by removing unnecessary energy loss and contributes to energy sustainability goals.

References

Al-Muhandes, R., Ali, S., & Faizal, M. (2023). Integration of IoT and photovoltaic systems for sustainable logistics. Journal of Cleaner Production, 412, 137524.

Bokolo Anthony Jnr (2023). Green campus paradigms for sustainability attainment in higher education institutions – a comparative study. Journal of Science and Technology Policy Management

D.D. Prasanna Rani, D. Suresh, Prabhakara Rao Kapula, C.H. Mohammad Akram, N. Hemalatha, (2023), IoT based smart solar energy monitoring systems, journal materials today proceedings

Imam Hossain, Md Shihabul Islam, Rabeya Sultana, Md.R. Rahman (2022), IoT Based Home Automation System Using Renewable Energy. American Journal of Agricultural Science, Engineering, and Technology (AJASET)SEDA Malaysia. (2023). Malaysia Solar Energy Report 2023. Putrajaya: Sustainable Energy Development Authority Malaysia.

Mani V; Ragul R; Raja M; Sujitha S; Sankaran S; Madhan Kumar C (2025). IoT-Enabled SolarBased Smart Street Lighting System Using ESP32 and Cloud Platforms. IEEE International Conference on Inventive Research in Computing Applications (ICIRCA)

Maryam Alghfeli; Meera Alnuaimi; Nouf Alsebaiha; Shamsah Alnuaimi; Bivin Pradeep; Parag Kulkarni (2022). DroParcel: Smart System for Secure Parcel Delivery. IEEE International Conference on Consumer Electronics - Berlin (ICCE-Berlin)

Muharemović, E., Banjanović-Mehmedović, L., & Džafić, E. (2021). Cost and performance optimization in parcel delivery systems. Promet – Traffic & Transportation, 33(1), 129–139.

Sustainable Energy Malaysia. (2023). Annual Renewable Energy Statistics Report 2023. Kementerian Tenaga, Sumber Asli dan Alam Sekitar (KETSA).

Yufei Wang, Jia-Wei Zhang,Kaiji Qiang, Runze Han, Xing Zhou,Chen Song,Bin Zhang,hatchai Putson, Fouad Belhora, Hajjaji Abdelowahed, (2024) IoT-based green-smart photovoltaic system under extreme climatic conditions for sustainable energy development, Global Energy Interconnection.