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International Journal for Modern Trends in Science and Technology, 9(05): 1-8, 2023

ISSN: 2455-3778 online
DOI: https://doi.org/10.46501/IJMTST0905001
Available online at: http://www.ijmtst.com/vol9issue05.html

IoT Based Thermoelectric Mini Cold Storage Unit Operated by Peltier Effect

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To Cite this Article
Konishka Santra, Soumajit Ghosh, Sudip Paul and Shairee Ganguly. IoT Based Thermoelectric Mini Cold Storage Unit Operated by Peltier Effect. International Journal for Modern Trends in Science and Technology 2023, 9(05), pp. 1-8. https://doi.org/10.46501/IJMTST0905001

Article Info
Received: 28 March 2023; Accepted: 28 April 2023; Published: 30 April 2023.

ABSTRACT

The diverse climate of India made certain the availability of all varieties of fresh fruits and vegetables. Based on the production of fruits and vegetables, India ranked 2nd in the world, but because of the hunger index, India was in the 101st position out of 116 countries in the world. The reason behind this was the food storing inability of India, which however, was damaging the quality of the fruits and vegetables, as nutritional losses and even spoilage of entire crops could occur, and also, in the same way, was declining the profit level of farmers. Depending on that situation, which system required less space, was portable, and could be controlled easily and more economically; there thermoelectric cold storage was the solution tothe before-mentioned problem, which was IOT based and able to monitor real-time temperature, relative humidity, and concentration of gas in cold storage and appraise the dangerous limits of these parameters. This cold storage system was operated by the Peltier effect. The absence of a compressor, invulnerability to leaks, noise, toxic refrigerant gas, etc. make this system more advanced and also suitable to fulfill the objective, i.e., to maintain a proper supply chain of fruits, vegetables, and crops to retain good quality.

Keywords:Fruits and vegetables, thermoelectric cold storage, Peltier effect

1. INTRODUCTION

Food safety is important to pre-empt food wastage as food is a basic necessity of all living beings. India has a novel geographical position and a massive variety of soil, therefore producing kinds of fruits and vegetables like apples, grapes, mango, papaya, bitter gourd, okra, potatoes, ginger, many more crops, and so on. A prominent number of organizations all over the world, namely the Food and Agriculture Organization (FAO), are finding out the large drawback of postharvest food losses[1]. Much of the developing world lacks access to reasonable refrigeration systems for pre-cooling, cold transport, cold storage, or cooling throughout postharvest handling and distribution of decayable foods.

The basic principle of refrigeration preservation is to lower the temperature of the food and maintain that temperature at a specified level. The harmful changes, such as the expansion of microorganisms, ripening, browning reaction, pigment degradation, and moisture loss, are stopped or significantly reduced [1]. Cold storage slows not only biological and chemical changes but also physical and microbiological changes that cause food spoilage [2]. As a result, it extends the storage life of food up to many weeks or months.

Otherwise, farmers get affected as they can't get any profit. They sell their product at a low price because they won't have any storage facilities. The consumers also get affected by this lack of age because crops get damaged during transportation and the left-over good crops are stored by the retailers, who sell them at a high price, which is sometimes not preferable.Large cold storage facilities are out of reach and unsuitable for small farmers. Mini Cold Store units are designed to provide a very innovative technology solution, to address the different temperature, space, handling, and humidity requirements, of various vegetables.

Moreover, the physical loss of food has multiple consequences in association with the wastage of inputs like water, fertilizer, electricity, human efforts, and precious time. To fulfill the worldwide food demand, in conjunction with increasing food production, efficient supply chain management has got to be adopted, and therefore the cold storage preservation of fruits and vegetables from harvest to the consumer has to be encouraged [3]. In this manner, it's needed to implement quality-observant devices at cold storage systems using the Internet of Things (IoT), sensors keep track of the natural factors that cause or accelerate the rot of the food. An android application that receives all information or data from hardware and shows it, the received data is kept in a database by using the web server concept. A web server within the database provides access to the program functions for the device through a tool web page by using the internet and also the system is well protected[4,5].

The thermoelectric mini cold storage unit converts energy into heat and vice-versa, with an inflexible structure, correct stability, excessive reliability, and no greenhouse gas emissions. To improve thermoelectric refrigeration systems that are primarily based on the Peltier effect for eliminating heat through the use of direct current (DC) through various substances connected, resulting in a temperature difference[6]. The thermoelectric refrigerator especially includes P and N-type semiconductors related together, and while DC is carried out throughout them, one junction will become heated, and the alternative will be cooled[1]. Rahmen et al. developed a system that might be able to generate a cold temperature of 10°C within the cooling chamber while maintaining a warm temperature of 40°C. Experiment results showed a greater coefficient of performance (COP) of roughly 0.61 for each cooling and heating effect. This was also created by Ibikunle et al. for the event of a 30 W single-stage thermo electrical cooler of 4-liter capacity that cools the vegetables from 27°C to 5°C in 3 hours[1].

Thus, to solve the growing concern of food wastage due to the lack of scientific cold chain infrastructure for rural fruit and vegetable vendors and the simultaneous increasing demand for fresh fruits and vegetables, a thermoelectric refrigeration system was designed and developed.

2. COMPONENTS

2.1Peltier Mechanism

A thermal control module called a Peltier module (thermoelectric module) has both warming and cooling effects. It is possible to alter the surface temperature and maintain it at the desired temperature by running an electric current through the module [7].

2.2 Heat Sink

It transports the heat that the electronic/mechanical device produces[8]. The heat sink is commonly referred to as a source of heat that consumes some amount of heat from the structure without affecting the enormous temperature.

2.3 Insulation materials

The device should be insulated to ensure effective cooling with a holder made of aluminum[8]. It lowers the discharge of ozone-depleting gases such as carbon dioxide.It ultimately proves to be a crucial factor in the ozone layer concerns related to drinking and other medical conditions.

2.4 DC Fan

This device is used to create a stream within the liquid and has cutting edges or vanes that follow the fluid and can control the speed as required by the situation[8].

2.5 Temperature sensor

A temperature sensor measures the temperature of its state and variations in the information in an electronic format for recording, display, or temperature fluctuations are an indication.

2.6 Cable assembly

A cable assembly is made up of one or more cables[8]. Assembly is optional and suitable for joining two devices, yet they could be a subpar item.

3. MANUFACTURING PROCESS

Firstly, a refrigeration chamber is made, for which a container is used with insulating materials (aluminum sheeting, 1 mm thick) on each side. The bottom of this container is made to the right measurement to fit the fin fan meeting in it. Also, fins are connected to fans, and the complete assembly is hooked up behind the refrigeration chamber. After the alignment of enthusiasts in that, a few holes in a piece of Styrofoam had been made in which they could input the primary compartment. Peltier Module is hooked up to the floor of the fin. The use of alcohol or similar substances should be used with caution to ensure that the module is free of dust and oily substances. Following that, an area for a snack shelf was created, and holes were cut to accommodate the enthusiasts. For the lightning, LED channels had been made with the use of a tiny piece of Styrofoam to cowl the top, and white LED strips had been used for this cause. The aluminum tape became popular for taping purposes because it appears better and is warmer to the touch. After that, the cable spacing changed, and the thermostat was connected. 12V DC electricity is used in this process, in which each of the enthusiasts and the module is hooked up to the circuit controller using wires. After hooking up the entire thing to the battery, a push-button was made and the outside is made with acrylic glass, a scoring knife is used to reduce that during straights[9].

3.1 IOT

Cold storageare dealing with perishable goods.The modern multi-target concept of food preservation is becoming more attractive with recent technologies to maintain their quality during storage [10,11]. These require critical monitoring as well as control of temperature and humidity.Instrumenting of cold storage facility with an IoT-enabled cold storage monitoring solution helps to record, monitor and maintain the conditions inside the facility regularly.

Problems faced in cold storage monitoring on various products that are kept in different sections of one facility require unique temperatures to be maintained to prevent decay and extend their shelf-life.There are some challenges for the cold storage monitoring systems, such as supporting distinct requirements for various products, tracking products and labeling, real-time monitoring, minimizing human intervention, and monitoring of various parameters. There are various attempts to integrate IoT with cold storage, and each of them has its contribution. Afreen and Bajwa [12] presented a real-time intelligent monitoring and notification system (RT-IMNS) based on IoT to introduce real-time monitoring of important parameters such as temperature, luminosity, humidity, and gas concentration in cold storage. Along with constant monitoring, whenever a deviation is detected, adjustments must be made immediately as weather changes and temperature fluctuations affect the environment and can have adverse effects on the stock.

3.2 Circuit Analysis

Humidity and temperature are common parameters to measure environmental conditions. In this Arduino-based project ambient temperature and humidity and display it on a PC screen. A combined temperature and humidity sensor DHT22 is used with Arduino to develop this Celsius scale thermometer and percentage scale humidity measurement.

This process consists of three sections -

i)One senses the humidity and temperature by using the humidity and temperature sensor DHT22. ii)The second section reads the DHT sensor module's output and extracts temperature and humidity values into a suitable number in percentage and Celsius scale. iii) The third part of the system displays humidity and temperature on the PC[12,13].

3.3 Circuit Diagram and Explanation

A liquid crystal display is used for displaying temperature and humidity and is directly connected to the Arduino in 4-bit mode. Pins of the LCD, namely RS, EN, D4, D5, D6, and D7, are connected to Arduino digital pin numbers 2, 3, 4, 5, 6, and 7. And a DHT22 sensor module is also connected to digital pin 12 of the Arduino with a 5K pull-up resistor[8]. This system is based on single-wire serial communication. First, the Arduino sends a start signal to the DHT module, and then the DHT module gives a response signal containing temperature and humidity data. Arduino collects and extracts them in two parts: humidity and temperature, and then sends them to a 16x2 PC. A sensor module, namely DHT22, features a humidity and temperature complex with a calibrated digital signal output, making it a combined module for sensing humidity and temperature[12].

DHT22 gives very precise values of humidity and temperature and ensures high reliability and long-term stability. This sensor has a resistive type humidity measurement component and an NTC-type temperature measurement component with an 8-bit microcontroller inbuilt that has a fast response, is cost-effective, and is available in a 4-pin single-row package[12].

This module sends data in the form of a pulse train for a specific period, and the whole process takes about 4 MPs. A complete 40-bit data transmission and the data format of this process are given below: 8-bit integral RH data + 8-bit decimal RH data + 8-bit integral T data + 8-bit decimal T data + 8-bit checksum.

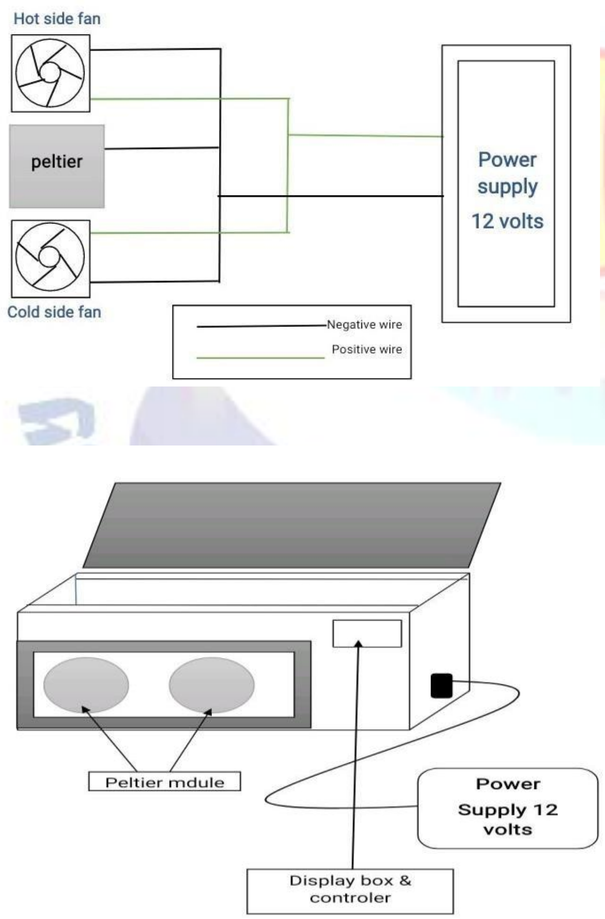

Fig 1: Circuit Diagram

3.4 Complete Process

Firstly, Arduino sends a high-to-low start signal to DHT22 with a 18µs delay to ensure DHT's detection. Arduino should pull up the data line and wait for 20-40µs for DHT's response. Once DHT detects a start signal, it will send a low-voltage response signal to Arduino with a time delay of about 80µs and pulls up the data line, and keeps it for 80µs for DHT's arranging of sending data. When data is at a low voltage level, it means that DHT22 is sending a response signal. Again, data line pull-up for 80µs for preparing data transmission.

DHT to Arduino, for every bit begins with 50µs low voltage, and the length of the high voltage level signal determines whether the data bit is "0" or "1". One important thing is to make sure the pull-up resistor value is correct because if we are placing the DHT sensor at a distance of 20 m, a 5K pull-up resistor is recommended. With this Arduino-based system, we can easily measure ambient temperature and humidity and control it[12].

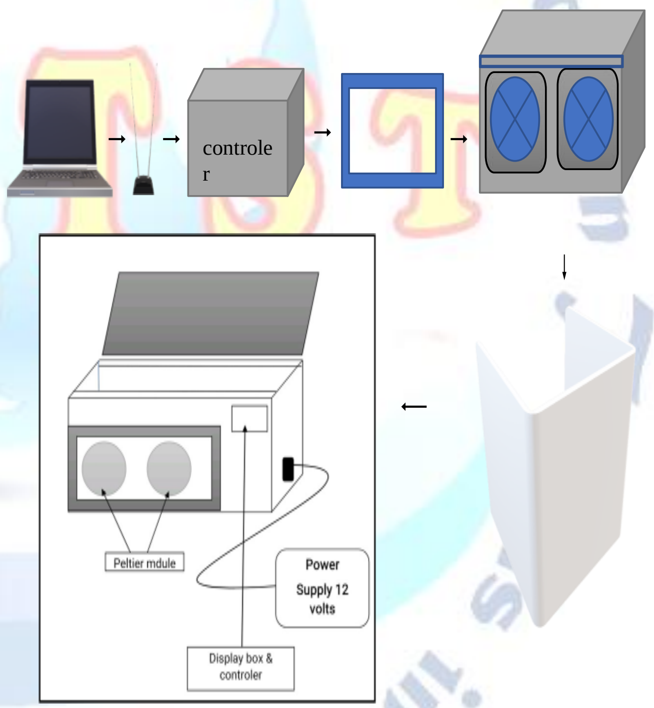

Fig 2: Flow diagram of the system

4. Advantages

4.1 Compactness

Thermoelectric fridges are the maximum compact due to the small length of the cooling components - cooling module/warmness sink.

4.2 Weight

These devices weigh 1/3 to 1/2 as an awful lot as the opposite devices due to the lightweight cooling system - no heavy compressor.

4.3 Portability

These devices are the maximum transportable due to the fact they may be mild sufficient to hold with one hand and aren't suffering from movement or tilting.

4.4 Price

These coolers value 20% - 40% much less than the equal-sized compressor or absorption devices to be had for leisure use.

4.5 Battery Drain

Thermoelectric has a most modern-day drain of 12 volts of 4.5 amps. Compressor portables draw barely greater modern-day whilst jogging however may also be common barely much less relying on thermostatic management settings. Absorption portables draw 6 -7.5 amp [14].

4.6 Cooling Performance

Compressor structures are probably the maximum green in hot weather. Some fashions will carry out as a transportable freezer and could refrigerate in ambient temperatures of as much as 101levels F. Thermoelectric devices will refrigerate in sustained ambient temperatures of as much as 95 levels F. If they may be saved full, they'll refrigerate satisfactorily even if sunlight hours temperatures attain a 101 levels F due to the fact the temperature of the contents will lag behind ambient. The meals can be simply beginning to heat up whilst the air cools off within side the night time which deliversthe temperature of the meal backpedal to normal [14].

5. RESULT AND DISCUSSION

Fruits and vegetables are safely edible when the temperature maintain at the time of storage.

5.1 Calculations

At that point, when checked with the temperature sensor the temperature kept up inside the cooler was = 5°C

We know the ambient temperature is = 25°C

Coefficient of performance (COP) = Refrigeration Effect / Work Input Relative

COP = Actual COP /Theoretical COP

Actual COP =14.10

Theoretical COP= (TH – TL) ....(1)

(25 + 273) – (5 + 273)

[to convert a Celcius temperature figure to Kelvin, add 273]

Theoretical COP = 20

Relative COP =Actual COP /Theoretical COP = (14.10/20)*100 =70.5%

When the machine is providing useful heating and cooling then

Combined COP = [| dQ_{cool} | + | dQ_{heat} |] /dW....(2)

(asdQ heat = dQ_{cool} + dW)

Combined COP = [(2 * | dQ_{cool} |)+ dW] /dW .....(3)

Compared to COP_{cool}=| dQ_{cool} |/dW

[Q representsheat and Represents as work done][15]

5.2 Effect of storage unit on Physiological Loss in Weight (PLW):

Fruits and vegetables are evaluated for post-harvest quality and shelf life using the PLW. It is a measurement of the weight loss a crop experiences over time as a result of physicochemical changes to the crop. The general rise in the PLW associated with the lengthening of storage time was related to crop species respiration, water transpiration through the tissues, and other physicochemical changes [16]. The weight of the crop decreases when fresh produce continues to respire while it is being stored due to carbon loss through the gas exchange during the respiration process and the transpiration of water vapor from the crop's surface[17].

5.3 Effect of storage conditions on Firmness:

The texture of vegetables has been used as a gauge of consumer acceptance of the product. The physical anatomy of the tissue, including cell size and shape, strength, and how cells link together to create a tissue and wall thickness, determines the firmness of fruits and vegetables[17]. In crops stored at higher temperatures, the process of tissue and cell wall breakdown accelerates. Higher relative humidity was found to have a greater impact on the crop's ability to maintain its firmness while being held at lower temperatures by preventing moisture transport and, ultimately, crop shrinkage[18].

5.4 Effect of storage condition on color:

One of the most noticeable visual characteristics of fruits and vegetables is color. The commodity's color is what first catches the eye of the consumer and determines its attractiveness to crops. Okra, bitter gourd, mango, and papaya had their surface colors measured to identify color changes brought on by physiochemical interactions and the ripening of fruits and vegetables during storage to as certain the impact of storage conditions and storage duration on the color of the crop. The color indicates the crop's varying levels of greenness and redness. Fruits and vegetables' green colorserves as a sign of how much chlorophyll is present in the crop[1,19].

While crops were stored in an enclosed chamber and under hygienic conditions, which prevented the external attack from microorganisms, the decrease in acceptability was caused by the growth of fungus and a blackish color in bitter gourd and okra, as well as the ripening of mango and papaya.

The basic guidelines and consideration, design, and characterization of mini cold storage units have not been developed yet rapidly. This gap is essential to be filled by engineers in the future.

(a) (b)

Fig 3: Effect of thermoelectric cold storage system on the visual appearance of pointed gourd [observed at (a) 0th-day storage and (b) 6th-day storage]

(c) (d)

Fig 4: Effect of thermoelectric cold storage system on the visual appearance of apple[observed at (c) 0th-day storage and (d) 6th-day storage]

5.5 Enhancement of shelf life

The performance of the thermoelectric refrigeration system was estimated based on the storage stability of fruits and vegetables. The freshly harvested summer fruits and vegetables were procured.Each crop was stored at thermoelectric refrigeration (temp 15–18 °C and RH 80–90%), and ambient atmospheric (temp 35–40 °C and RH 40–50%) storage conditions, respectively[1]. Every day, five crops from each storage condition were selected randomly for quality analysis. The storage stability of the commodities stored in the developed refrigeration system was compared with the under ambient environmental conditions. Based on that two tables are formed which show the difference between the shelf life of the fruits and vegetables when they are stored in refrigeration and ambient environment.

Table 1: Shelf life of Fruits[20]

Fruits	Fridge Shelf Life	Pantry (Cool and Dark)
Apples	1-2 Months	2-3 Weeks
Avocados	7-14 Days	3 Days
Bananas	Don't Refrigerate	7 Days (If Green), 3-4 if Ripe
Citrus	2+ Weeks	1-2 Weeks
Pears	2 Weeks	3-5 Days
Berries	2-4 Days (isolated and covered)	Don't Store in Pantry
Watermelon	6-8 Days	2-3 Days

Table 2: Shelf life of Vegetables[20]

Vegetable	Fridge Shelf Life	Pantry (Cool and Dark)
Beans	3-6 Days	Don't Store in Pantry
Cabbage	1 Month	Don't Store in Pantry
Carrots	1-2 Months	Don't Store in Pantry
Celery	2-3 Weeks	Don't Store in Pantry
Corn	3-4 Days	Don't Store in Pantry
Onions	1-3 Months	1-3 Months
Potatoes	Don't Refrigerate	2-4 Months
Tomatoes	5-7 Days	5-7 Days

6. CONCLUSION

An eco-friendly thermoelectric mini-cold storage unit or container of 100-liter capability supported the

Peltier result was developed, and therefore the performance was evaluated for keeping the standard of fruits and vegetables as compared to constant hold on at ambient temperature.The thermoelectric cold storage unit may be operated at a temperature range of 15-17°C and a ratio of 80–90%, which approaches the storage conditions needed for many summer fruits and vegetables [1]. It made possible spectacular results for the quality retention of fruits and vegetables throughout storage. Bitter gourd, okra, papaya, mango, and grapes had a hyperbolic shelf life of 7-12 days when kept cool with electricity. So, it was concluded that adequate scope exists for the employment of the developed thermo- electrical cooling system for the cold storage of fruits and vegetables. As there's an absence of scientific cold storage infrastructure for maintaining the standard quality of fruits and vegetables throughout transportation in rural areas the thermoelectric cold storage unit or container isn't solely useful for generating carbon credits, but conjointly facilitates cold chain management of decayable crops [1].

Acknowledgment

It is of our great privilege to express our sincerest regards to our college to Guru Nanak Institute of Technology, JIS Group for financial support, valuable guidance, encouragement, and wholehearted cooperation.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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