VOL. 08 NO. 5,
MAY, 2025
E-ISSN 3027-1339
P-ISSN 3026-8257

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Systematic, Evaluation and Diversity Engr. (JSEDE)

Design and Implementation of a Solar-Powered Refrigerator with Automated Doors Controlled by an Android Application Using Arduino Mega2560 and Bluetooth Module

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DOI: https://doi.org/10.70382/ajsede.v7i5.013

Abstract

The design and construction of a solar-powered refrigerator with automated doors managed by an Android application utilizing an Arduino Mega2560 and a Bluetooth module constitute the focus of this research study. This was achieved by using a 12V DC 3000 rpm compressor, which does not require an inverter because it runs straight off of a 12V 180Ah battery that is charged by a solar 12V PV panel. The system consists of an Arduino Mega2560 Pro board, three 12V DC 92 RPM motors for the movement of the refrigerator doors and internal tray, MPU6050 temperature sensors, a 16x2 LCD display unit, an HC-06 Bluetooth module, an Android application created using MIT App-inventor, and a high current motor driver. Access to the refrigerator is limited because the system can only be accessed via the Android application. This document also includes an examination and evaluation of the features of the system that was created. The designed system improves user experience and is easy to use.

Keywords: Android Application, Automated Refrigerator, Compressor, Arduino, Bluetooth module.

Introduction

Fossil fuel scarcity has increased the demand for more dependable energy sources with a faster rate of depletion. Alternatives to non-renewable energy

sources, which are likely to have negative effects on both humans and plants on the planet, include renewable energy options that harness natural energy sources like solar energy, oceans, rain, wind, and steam from the Earth's crust. Out of all these energy sources, solar electricity is the most valuable resource for energy generation (Olaleye et al., 2020).

According to Washington Taylor, a physics professor at MIT who co-teaches a course on the physics of energy, the sun has a vast potential for energy. The Earth receives 173,000 terawatts, or trillions of watts, of solar energy per day. That is over ten thousand times the amount of energy used worldwide. Furthermore, that energy is entirely renewable, at least for the sun's lifespan. According to Taylor, the question that arises is "How big is the engineering challenge to harness the energy potential of the sun?" as solar energy is, at least theoretically, sufficient to supply all of humanity's energy needs (Chandler, 2011).

The most often used appliance in the home for storing food and beverages is the refrigerator, which is a necessary piece of equipment. Appliances used in kitchens have been significantly impacted by technological advancements. The refrigerator has improved human convenience by preserving food freshness and reducing spoiling. Since keeping items cool is a refrigerator's primary purpose and consumers did not require any extra features that would raise the price of a product, there hasn't been much improvement in features over time. However, more recently, refrigerators with enhanced capabilities have been established, which are not so common to many persons(Mohammed & R. Rajesh, 2019).

Significance of the Study

In a developing nation like Nigeria that struggles with power availability, discovering an expired or spoiled item in the refrigerator is a common concern. It can be discouraging to see someone with an item you put in the refrigerator for a specific reason. Traditional refrigerators don't provide security or control; in a medical facility or scientific lab, sensitive items like chemicals and drugs must be kept out of the hands of unauthorized workers. How can a refrigerator be used by someone with a disability?

In this paper, a solar-powered refrigerator built on an Arduino Mega2560 is presented as a technical fix for every issue that was previously discussed. The suggested solar-powered refrigerator might only be able to be operated through an Android application, meaning that only those who have access to the app can use the system.

Study Outline

Section I covers the subject matter's background, the report's significance, and its outline.The structure of this document is as follows. Similar refrigerators are covered and summarized in Section II. Section III presents the requirements, system architecture, and development approach. The system's implementation, testing, results of the test and

discussion is covered in Section IV. In Section V, the paper's conclusion is given.APA reference style is used to cite the sources in this paper.

LITERATURE SURVEY

Modern technology has greatly eased human existence. Below are some works on refrigerator similar to what we achieved here.

Intelligent Refrigerator using Machine Learning and IoT proposed by Rajeswari et al. (2022). This work determines the quality of fruits available in the refrigerator. The quality of the fruits that are kept in the refrigerator is determined by this operation. The food is categorized as spoiled or not spoiled by the intelligent refrigerator. The temperature, humidity, and gas sensors in the intelligent refrigerator sense voltage changes caused by different gases created by the food items. ADS1115 IC is coupled to the Raspberry Pi, which converts analogue signals into numerical values and uses machine learning techniques to classify sensor data. Using a Wi-Fi module that is connected to the Raspberry Pi for remote access, the classified output is delivered to the cloud.

Design and Development of a Solar-powered Picnic Refrigerator by Olaleye et al. (2020). A solar-powered vapour compression refrigeration system, which finds application in outdoor activities, has been developed in this work. The system was developed by integrating solar and cooling components such as a solar panel, a hybrid inverter and charge controller, a compressor battery, an evaporator, a condenser and a wire link. The system was tested during the day for 180 minutes at a time interval of 15 minutes and at night for 150 minutes at a time interval of 15 minutes to determine its cooling capacity, and it was discovered that it took more time to cool the cooling chamber during the day than at night. The 100MAH battery used in the experiment lasted two and a half hours, which was enough to cool the refrigerator.

Design and Implementation of Intelligent Refrigerator proposed by Rahman et al. (2023). Although not implemented as at the time of the publishing of report. The system consisted of several sensors to collect data both internally and externally. For the notifications and continuous monitoring an LCD screen and IP camera were incorporated. the system was also equipped with an android application to make the system more user friendly.

Jabbar et al. (2022), Solar Powered DC Refrigerator for Small Scale Applications. According to this research work a DC compressor of 12 V/80 W, 12 V/50 Ah battery, a pair of 12 V/175 W solar panels connected in parallel through a 10 A charge controller was used for the refrigerator. Temperature was programmed to monitor and control the switching states of the DC compressor.ATMEGA16 microcontroller with temperature, weight and momentary sensors interfacing was programmed in C language to control and monitor the ON/OFF states of the DC compressor. the result show that power consumption is reduced as an average of 30.21 W.

SYSTEM ARCHITECTURE

Methodology

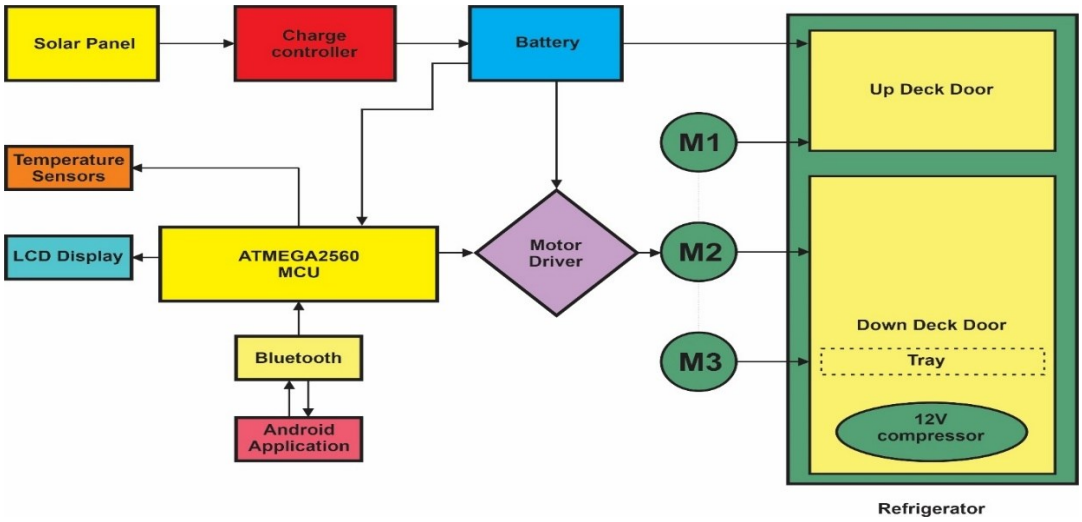


Figure 1: Block diagram of the solar powered refrigerator

This system is fully solar-powered with a backup battery. The basic block diagram for this task, which uses a solar panel, battery, and controller, is depicted in Figure 1. The design and implementation of an Android application-controlled solar-powered refrigerator are the goals of this project.

There are two sections to the refrigerator: a down deck and an up deck (freezer). The Android application is the only way to gain access to the doors of both compartments, ensuring security and preventing unauthorized individuals from access. The Android app also controls the tray located inside the lower deck, further enhancing the refrigerator's automated features.

The system consists of an Arduino Mega2560 Pro board, three number of 12V DC 92 RPM motors for the movement of the refrigerator doors and internal tray, MPU6050 temperature sensors, a 16x2 LCD display unit, an HC-06 Bluetooth module, an Android application created using MIT App-inventor, and a high current motor driver.

Materials Required

1. Arduino Mega2560



Figure 2: Arduino Mega 2560 Rev3

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analogue inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

2. HC-06 Bluetooth module

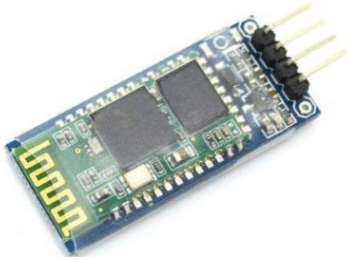


Figure 3: HC-06 Bluetooth module

HC-06 is a Bluetooth module designed for establishing short range wireless data communication between two microcontrollers or systems. The module works on Bluetooth 2.0 communication protocol and it can only act as a slave device. This is cheapest method for wireless data transmission and more flexible compared to other methods and it even can transmit files at speed up to 2.1Mb/s.

3. LCD display unit



Figure 4: 16x2 LCD display unit

An LCD screen is an electronic display module that uses liquid crystal to produce a visible image. The 16×2 LCD display is a very basic module commonly used in DIYs and circuits. The 16×2 translates a display of 16 characters per line in 2 such lines

4. MPU6050 temperature sensors

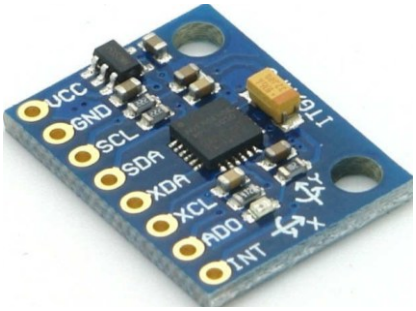


Figure 5: MPU6050 module

The MPU-6050 is a gyroscope and accelerometer. Along with angular velocity, it measures acceleration on the x, y, and z axes. The ambient temperature is also measured by this module. I2C is the communication protocol used by this sensor module.

5. MIT Appinventor

MIT App Inventor is a simple, visual programming environment that enables anyone, including children, to create fully working apps for smartphones and tablets.This software was used to build the application of the project. It was used to create the interface of the project.

6. Geared motor



Figure 6: Windscreen wiper motor

A gear assembly is attached to a geared DC motor. The speed of a motor is measured in rotations of the shaft per minute, which is known as RPM. The gear assembly aids in boosting torque while decreasing speed. The motor is a 12V 92RPM DC motor. This motor is coupled to a transmission mechanism which opens and closes the door on press of the buttons in the App.

Other components include the;

7. Solar PV components (PV modules, Charge controller and DC power storage device)
8. 12V DC compressor
9. R-134a Refrigerant

SYSTEM DESIGN

Sizing of PV component

Table 1: Load analysis of system

S/N	Load Description	Quantity	Power Rating (W)	Total Power (Watt x Quantity) (W)	Operational hours per Day (h/day)	Energy Used (Wh/day)
	Compressor	1	78	78	12	936
	DC motor	3	27	81	4	324
	Other components	-	5	5	12	60
	Total			**164**		**1320**

System voltage 12V *(this is determined by the DC loads).*
Peak Sun Hours, PSH 5.5 hours *(for Northern Nigeria)*
Assumptions
System losses 30% or 1.3
Battery autonomy day 3 days
DOD 80%
Sizing of solar panels
Effective load demand, ELD = Energy used (Wh/day) x system loss = 1320 Wh/day x 1.3 = 1716 Wh/day

$$\text{ELD in Ah/day} = \frac{\text{ELD (Wh/day)}}{\text{System voltage}} = \frac{1716}{12} = 143 \text{ Ah/day}$$

$$\text{Array current} = \frac{\text{ELD (Ah/day)}}{\text{PSH}} = \frac{143}{5.5} = 26 \text{ A}$$

$$\text{Number of modules in series} = \frac{\text{System voltage}}{\text{Nonimal voltage of PV mondule}} = \frac{12}{12}$$

$$= 1 \text{ number of module in series}$$

$$\text{Number of modules in parallel} = \frac{\text{Array current}}{I_{MP} \text{ of module}} = \frac{26}{8.03}$$

$$= 3.2;\ 4 \text{ number of modules in parallel}$$

$$\text{Total number of modules in the array} = \text{modules in series} \times \text{modules in parallel}$$

$$= 1 \times 4 = 4 \text{ modules in the array}$$

Therefore, 4 number of 250Wp panel is required. This means that 1 module will be connected in series of 4 strings of parallel connection
Battery Sizing

$$\text{Battery Capacity} = \frac{\text{ELD Ah/day} \times \text{Autonomy Day}}{\text{DOD}} = \frac{143 \times 3}{0.8} = 536.25 \text{ Ah}$$

$$\text{Number of batteries required} = \frac{\text{Battery capacity}}{\text{battery Ah rating}} = \frac{536.25}{180} = 3$$

Therefore, 3 number of 180Ah battery is required for this design

$$\text{Battery in series} = \frac{\text{System Voltage}}{\text{Battery Nominal Voltage}} = \frac{12}{12} = 1 \text{ number of battery in series}$$

$$\text{Battery in parallel} = \frac{\text{Number of Battery}}{\text{Number of Battery in series}} = \frac{3}{1} = 3 \text{ batteries in parrellel}$$

This means that 1 number of 180Ah 12V battery will be connected in series of 3 strings of parallel connection
Charge Controller Sizing
Charger controller voltage match the system voltage of 12V

Charge controller Ampere Rating

$$= \text{Short circuit} \times \text{system loss} \times \text{number of panels}$$

$$\text{Charge controller Ampere Rating} = 8.50 \times 1.3 \times 4 = 44.2\ \text{A}$$

Therefore, a 45A 12V charger controller is required

Determining the Volume of Refrigerator Compartments

Up deck Volume: Height = 403 mm; Length = 428 mm; Depth = 348 mm

Volume of Up deck = H x L x D = 60024432 mm^3

Down deck Volume: Height = 960 mm; Length = 428 mm; Depth = 460 mm

Volume of Down deck = 189,004,800 mm^3

Total volume = 60024432 mm^3 + 189,004,800 mm^3 = 249,029,232 mm^3

Table 2: PV module characteristics

Electrical Characteristics	**Value**
Maximum Power at STC (P_{MAX})	250W
Nominal voltage (V_N)	24V
Optimum Operating Voltage (V_{MP})	31.14V
Optimum Operating Current (I_{MP})	8.03A
Open Circuit Voltage (V_{OC})	37.32V
Short Circuit Current (I_{SC})	8.50A
Maximum System Voltage DC	600V
Maximum Series Fuse Rating	15A
Power Tolerance	±5%

SECTION V: SYSTEM OPERATION

The circuit consists of motor driver for control of the DC motors, temperature sensors for temperature monitoring, LCD display unit, Bluetooth module for communication with the Android application. The microcontroller plays a central role in this system and serves as the intelligent component of the system. 12V power is supplied to the system when the control switch is manually turned 'ON'. The microcontroller performs system initialization, during this task the microcontroller checks the status of the 'Doors'; updates the temperature status of both the up and down decks on the display screen. The initialization task takes around 200-500 millisecond.

At this point the Android App can be connected to the system via Bluetooth. On the app the 'Connect' button is pressed. The user must select the appropriate address (**98:DA:60:05:6E:B1 HC-06**) unless the connection will not be successful. Once the connection is deemed successful the microcontroller sends the update of the system status to the App. The App interface changes to notify the user of the new status.

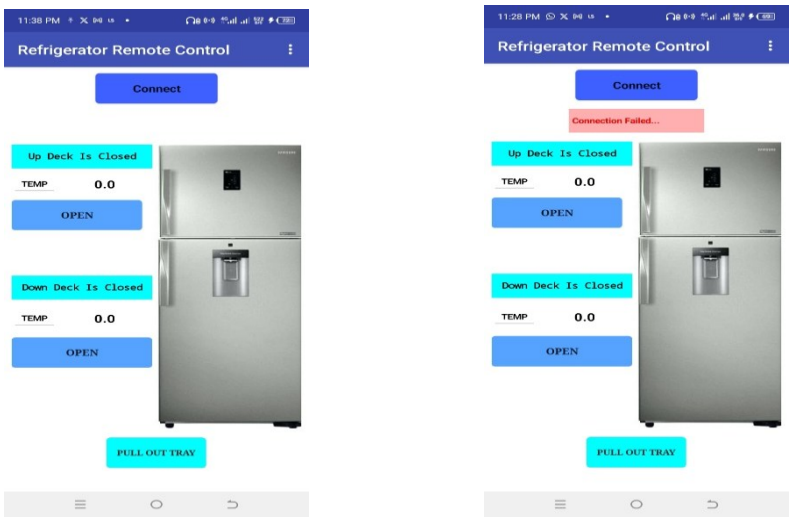
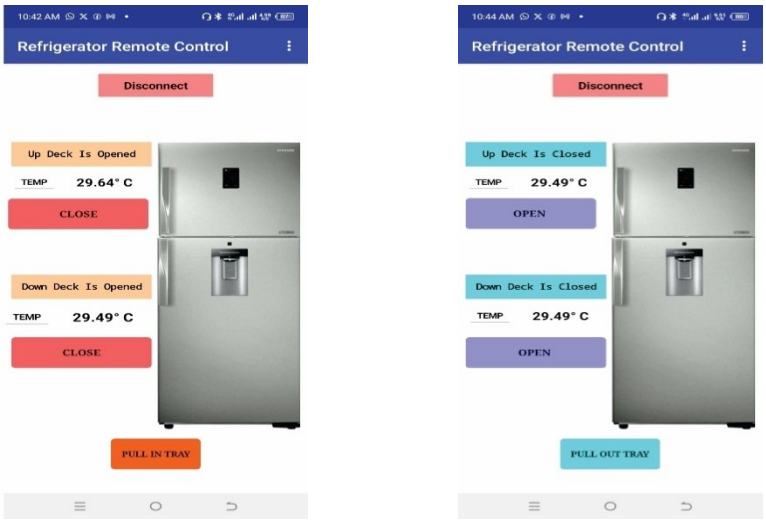


Figure 7: App interface before connection is established (left) and Connection failed (right)

Figure 7 and 8 shows the App interface when different commands are given. When the designated button on the App is pressed it sends signal to the MCU on the control circuit via the Bluetooth module transceiver, this signal prompts the DC motors for either forward or backward rotation. With the aid of limit switches the doors opens to distance equal to 90^0. The motor is coupled to a transmission mechanism which opens and closes the door on press of the buttons in the App. In the case of the tray, a third DC motor, along with plastic rollers aid the movement of the tray whether in or out.

The MCU was programmed using Arduino IDE version 2.2.1. The App is designed with MIT App Inventor. The flowchart of the system algorithm is available in figure 9.



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Figure 8: App interface; doors open and tray out (left) and doors closed and tray in (right)

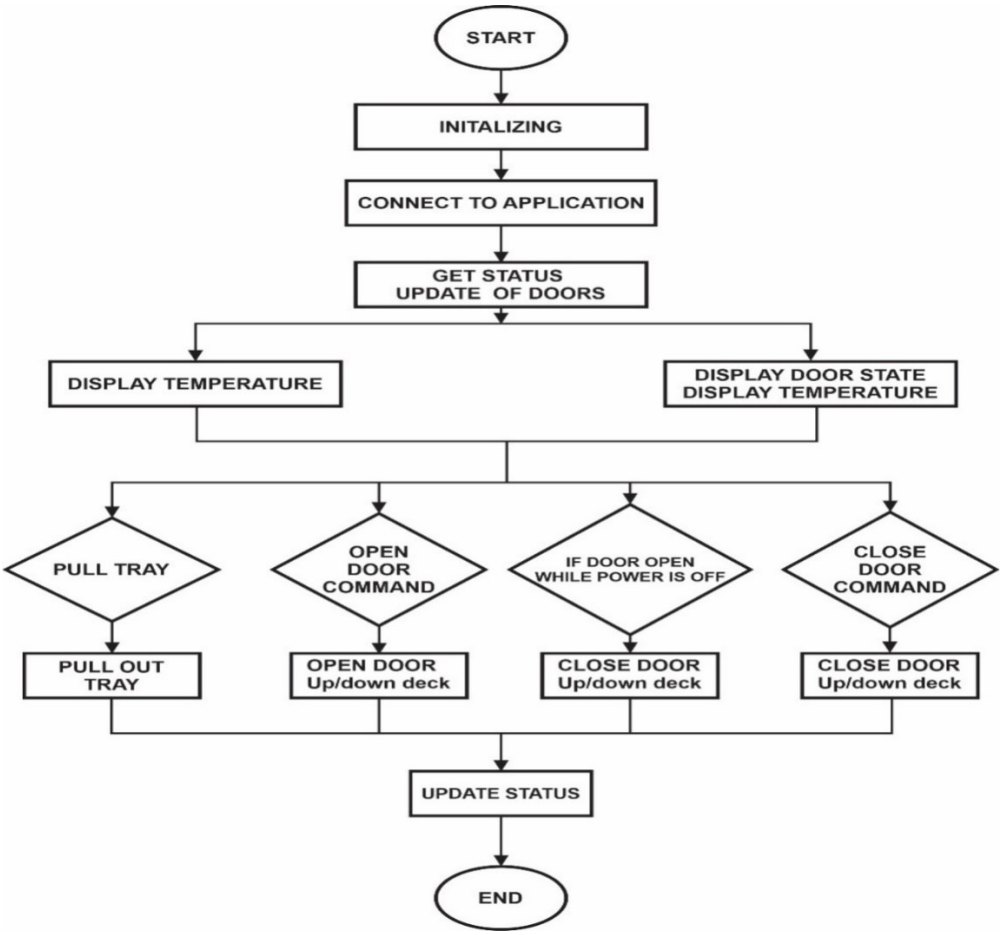


Figure 9: Flowchart of system



Figure 10: front view of refrigerator (open and closed)

TESTING AND RESULT

Testing

As with every science project it is pertinent that test be carried out after the design and implementation phase of an idea is achieved. The test was conducted to achieve the following objectives;

1. To observe the operation of the system over a 6-hour period
2. To know how long it will take to reach 0^0C (up deck)
3. To know how much power(watt) the system consumes at any given time
4. To power the system with one 180Ah 12V lead-acid battery.
5. To observe the system characteristics with content and without content over a period of 6-hours
6. To determine the following:
    a. Energy delivered by the PV panel
    b. Power input to the compressor
    c. Coefficient of performance

Test Procedure

The test was conducted for a 6-hour period and readings were measured and recorded at interval of ten minutes. The quantities measured include; current drawn from the battery; battery voltage, temperature of up deck; temperature of down deck. For a period of three days each, test was conducted without content in the refrigerator and with content in the refrigerator. The ambient temperature reading was recorded at an hourly interval during the 6-hour test period.

Test apparatus include;

1. 180AH 12V Lead-acid battery (contrary to our design calculation above which required that three of these battery-type be used),
2. Multimeter and
3. Clamp-meter.

RESULTS

With content in the refrigerator

Table 3: Test data table 1

Time	V (13.34)	I	W	UP (27.25)	DOWN (28)	Ambient Temperature
00:00	13.06	8.42	109.97	27.25	28	27.30
00:10	12.80	6.51	83.33	24.65	27	-
00:20	12.78	7.10	90.74	22.11	26	-
00:30	12.74	6.98	88.93	19.56	26	-
00:40	12.72	7.16	91.08	17.40	25	-
00:50	12.70	6.97	88.52	15.24	24	-
01:00	12.69	7.54	95.68	13.40	24	27.80

Time	V (13.34)	I	W	UP (27.25)	DOWN (28)	Ambient Temperature
01:10	12.66	7.45	94.32	11.19	23	-
01:20	12.65	7.47	94.50	10.76	22	-
01:30	12.50	7.67	95.88	9.31	22	-
01:40	12.51	7.19	89.95	7.75	21	-
01:50	12.50	7.36	92.00	6.01	21	-
02:00	12.54	8.12	101.82	4.46	20	28.40
02:10	12.53	8.01	100.37	3.80	20	-
02:20	12.52	8.09	101.29	3.24	19	-
02:30	12.50	8.10	101.25	2.72	19	-
02:40	12.51	7.03	87.95	2.29	19	-
02:50	12.48	7.41	92.48	2.01	19	-
03:00	12.46	7.99	99.56	1.68	18	28.60
03:10	12.46	8.07	100.55	1.31	18	-
03:20	12.43	7.99	99.32	1.02	18	-
03:30	12.42	8.04	99.86	0.69	18	-
03:40	12.40	8.08	100.19	0.51	18	-
03:50	12.39	8.03	99.49	0.27	17	-
04:00	12.38	8.00	99.04	-0.01	17	28.80
04:10	12.37	8.05	99.58	-0.34	17	-
04:20	12.35	8.01	98.92	-0.58	16	-
04:30	12.34	8.03	99.09	-0.86	16	-
04:40	12.33	8.05	99.26	-1.05	16	-
04:50	12.32	7.97	98.19	-1.14	16	-
05:00	12.31	8.00	98.48	-1.47	16	28.80
05:10	12.30	7.99	98.28	-1.71	15	-
05:20	12.29	7.98	98.07	-1.89	15	-
05:30	12.30	7.92	97.42	-2.04	16	-
05:40	12.28	7.95	97.63	-2.13	15	-
05:50	12.27	7.91	97.06	-2.41	15	-
06:00	12.26	7.90	96.85	-2.60	15	28.90
Average Current consumption			7.74			
Average power consumption			96.67			

Table 4: Test data table 2

Time	V (13.52)	I	W	UP (27.86)	DOWN (28)	Ambient Temperature
00:00	12.82	9.73	124.74	27.86	28.00	27.10
00:10	12.75	7.37	93.97	26.91	28.00	-
00:20	12.75	6.97	88.87	24.22	27.00	-
00:30	12.75	7.19	91.67	21.59	26.00	-
00:40	12.72	7.31	92.98	18.91	26.00	-
00:50	12.72	7.40	94.13	17.02	25.00	-
01:00	12.70	7.66	97.28	15.24	24.00	28.20
01:10	12.70	7.66	97.28	14.15	24.00	-
01:20	12.63	7.69	97.12	12.69	25.00	-
01:30	12.61	8.37	105.55	10.20	23.00	-
01:40	12.59	8.39	105.63	8.36	22.00	-
01:50	12.58	8.16	102.65	7.56	22.00	-
02:00	12.57	8.33	104.71	6.76	22.00	28.70

Time	V (13.52)	I	W	UP (27.86)	DOWN (28)	Ambient Temperature
02:10	12.55	8.21	103.04	6.20	21.00	-
02:20	12.54	8.31	104.21	5.64	21.00	-
02:30	12.52	8.19	102.54	5.16	20.00	-
02:40	12.51	8.27	103.46	4.69	20.00	-
02:50	12.50	8.25	103.13	4.22	20.00	-
03:00	12.49	8.22	102.67	3.89	19.00	29.20
03:10	12.47	8.15	101.63	3.47	19.00	-
03:20	12.46	8.18	101.92	3.24	19.00	-
03:30	12.46	8.14	101.42	2.86	19.00	-
03:40	12.43	8.12	100.93	2.62	19.00	-
03:50	12.42	8.17	101.47	2.29	19.00	-
04:00	12.42	8.14	101.10	2.06	19.00	29.60
04:10	12.41	8.14	101.02	1.86	19.00	-
04:20	12.42	8.15	101.22	1.54	18.00	-
04:30	12.40	8.17	101.31	1.26	18.00	-
04:40	12.36	7.58	93.69	1.02	18.00	-
04:50	12.34	8.13	100.32	0.74	19.00	-
05:00	12.34	8.16	100.69	0.55	18.00	29.80
05:10	12.37	8.07	99.83	0.27	18.00	-
05:20	12.31	8.08	99.46	0.04	18.00	-
05:30	12.30	8.01	98.52	-0.11	17.00	-
05:40	12.29	8.09	99.43	-0.39	17.00	-
05:50	12.28	8.08	99.22	-0.72	17.00	-
06:00	12.27	7.96	97.67	-0.95	17.00	29.50
Average Current consumption			8.03			
Average power consumption			100.45			

Table 5: Test data table 3

Time	V (13.12)	I	W	UP (29.49)	DOWN (29)	Ambient Temperature
00:00	12.88	7.85	101.11	29.49	29.00	27.90
00:10	12.89	2.43	31.32	29.07	28.00	-
00:20	12.66	7.22	91.41	26.67	28.00	-
00:30	12.66	7.09	89.76	24.60	27.00	-
00:40	12.66	7.28	92.16	22.29	26.00	-
00:50	12.65	7.33	92.72	19.94	25.00	-
01:00	12.62	7.67	96.80	16.74	24.00	28.50
01:10	12.60	7.95	100.17	15.42	24.00	-
01:20	12.57	8.17	102.70	13.47	23.00	-
01:30	12.55	8.36	104.92	11.19	23.00	-
01:40	12.55	8.39	105.29	9.68	21.00	-
01:50	12.53	8.57	107.38	8.74	21.00	-
02:00	12.52	8.25	103.29	7.80	21.00	29.20
02:10	12.50	8.41	105.13	7.28	20.00	-
02:20	12.48	8.47	105.71	6.52	20.00	-
02:30	12.48	8.33	103.96	6.34	20.00	-
02:40	12.46	8.47	105.54	5.78	19.00	-
02:50	12.48	8.67	108.20	5.35	19.00	-

Time	V (13.12)	I	W	UP (29.49)	DOWN (29)	Ambient Temperature
03:00	12.43	8.48	105.41	4.88	19.00	29.70
03:10	12.42	8.57	106.44	4.51	19.00	-
03:20	12.42	8.24	102.34	4.22	18.00	-
03:30	12.40	8.37	103.79	4.04	18.00	-
03:40	12.39	8.42	104.32	3.60	18.00	-
03:50	12.38	2.25	27.86	4.51	18.00	-
04:00	12.38	8.12	100.53	5.26	19.00	30.40
04:10	12.37	8.23	101.81	4.08	18.00	-
04:20	12.36	8.17	100.98	3.28	18.00	-
04:30	12.35	8.33	102.88	2.76	18.00	-
04:40	12.34	8.22	101.43	2.25	18.00	-
04:50	12.33	8.52	105.05	1.96	17.00	-
05:00	12.30	8.50	104.55	1.59	17.00	30.50
05:10	12.29	8.55	105.08	1.26	17.00	-
05:20	12.27	8.52	104.54	0.93	17.00	-
05:30	12.26	8.44	103.47	0.74	17.00	-
05:40	12.25	8.47	103.76	0.32	16.00	-
05:50	12.24	8.47	103.67	0.17	16.00	-
06:00	12.23	8.42	102.98	-0.06	16.00	31.10
Average Current consumption			7.90			
Average power consumption			98.34			

Without content in the Refrigerator

Table 6: Test data table 1

Time	V (12.53)	I	W	UP (26.72)	DOWN (26)	Ambient Temperature
00:00	12.33	7.80	96.17	26.72	26.00	26.50
00:10	12.24	6.74	82.50	23.71	27.00	-
00:20	12.34	6.83	84.28	20.27	27.00	-
00:30	12.33	6.94	85.57	16.34	26.00	-
00:40	12.30	7.03	86.47	12.84	25.00	-
00:50	12.29	6.93	85.17	9.92	24.00	-
01:00	12.28	7.42	91.12	7.09	23.00	26.80
01:10	12.26	7.17	87.90	4.27	22.00	-
01:20	12.25	7.39	90.53	1.69	20.00	-
01:30	12.24	7.31	89.47	-0.69	18.00	-
01:40	12.23	7.29	89.16	-2.37	17.00	-
01:50	12.23	7.05	86.22	-3.87	14.00	-
02:00	12.21	7.29	89.01	-5.09	13.00	27.20
02:10	12.20	7.20	87.84	-6.46	12.00	-
02:20	12.19	7.02	85.57	-7.54	11.00	-
02:30	12.18	7.07	86.11	-8.39	10.00	-
02:40	12.17	7.05	85.80	-9.38	10.00	-
02:50	12.16	7.06	85.85	-10.88	9.00	-
03:00	12.15	7.07	85.90	-11.07	9.00	27.80
03:10	12.14	7.05	85.59	-11.92	9.00	-
03:20	12.13	6.97	84.55	-12.53	9.00	-
03:30	12.13	7.00	84.91	-13.19	10.00	-
03:40	12.12	6.86	83.14	-13.75	9.00	-

Time	V (12.53)	I	W	UP (26.72)	DOWN (26)	Ambient Temperature
03:50	12.11	6.87	83.20	-14.41	10.00	-
04:00	12.10	6.82	82.52	-14.84	9.00	28.60
04:10	12.09	6.75	81.61	-15.26	10.00	-
04:20	12.08	6.68	80.69	-15.54	10.00	-
04:30	12.07	6.76	81.59	-15.78	10.00	-
04:40	12.08	6.77	81.78	-16.06	11.00	-
04:50	12.05	6.09	73.38	-16.20	11.00	-
05:00	12.04	6.84	82.35	-16.25	11.00	28.50
05:10	12.04	6.76	81.39	-16.34	11.00	-
05:20	12.03	6.75	81.20	-16.29	10.00	-
05:30	12.01	6.72	80.71	-16.48	11.00	-
05:40	12.00	6.51	78.12	-16.44	11.00	-
05:50	12.00	6.81	81.72	-16.44	11.00	-
06:00	11.99	6.78	81.29	-16.58	11.00	28.50
Average Current consumption			6.96			
Average power consumption			84.61			

Table 7: Test data table 2

Time	V (13.23)	I	W	UP (27.19)	DOWN (27)	Ambient Temperature
00:00	12.88	7.32	94.28	27.19	27.00	26.30
00:10	12.88	6.45	83.08	24.51	27.00	-
00:20	12.82	6.26	80.25	21.54	27.00	-
00:30	12.81	6.46	82.75	18.15	25.00	-
00:40	12.78	6.49	82.94	15.00	24.00	-
00:50	12.75	6.54	83.39	11.49	23.00	-
01:00	12.73	6.62	84.27	9.49	22.00	26.40
01:10	12.71	6.74	85.67	6.53	20.00	-
01:20	12.69	6.78	86.04	3.85	19.00	-
01:30	12.68	6.94	88.00	1.92	18.00	-
01:40	12.66	6.74	85.33	-0.25	16.00	-
01:50	12.65	6.66	84.25	-1.94	15.00	-
02:00	12.63	6.77	85.51	-3.02	14.00	27.30
02:10	12.63	6.62	83.61	-4.62	13.00	-
02:20	12.61	6.69	84.36	-5.52	12.00	-
02:30	12.60	6.64	83.66	-6.51	11.00	-
02:40	12.59	6.04	76.04	-7.21	11.00	-
02:50	12.57	6.63	83.34	-8.06	10.00	-
03:00	12.57	6.62	83.21	-9.00	10.00	27.90
03:10	12.54	6.57	82.39	-9.56	10.00	-
03:20	12.53	6.55	82.07	-10.41	10.00	-
03:30	12.51	6.73	84.19	-11.02	10.00	-
03:40	12.51	6.79	84.94	-11.73	10.00	-
03:50	12.51	6.51	81.44	-12.20	10.00	-
04:00	12.50	6.47	80.88	-12.72	10.00	28.50

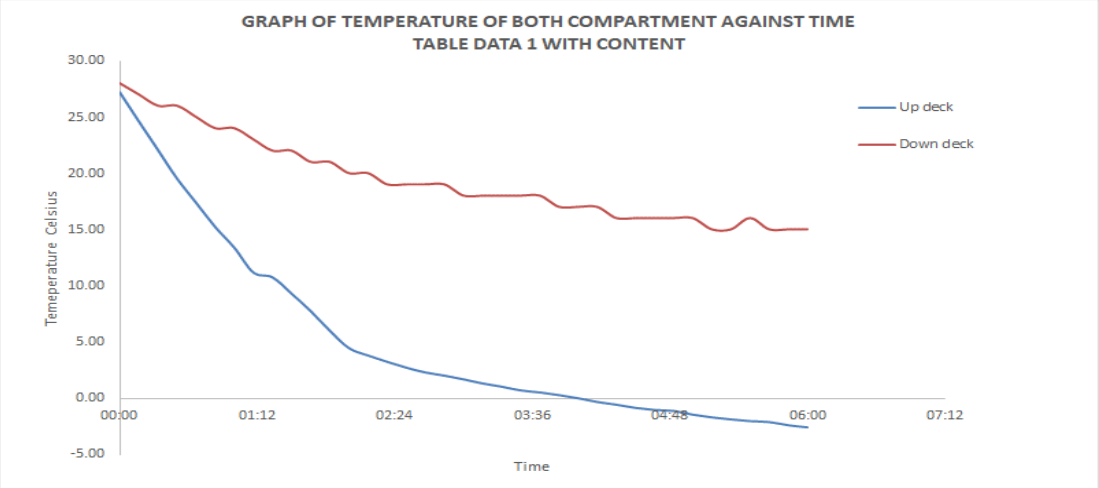
Time	V (13.23)	I	W	UP (27.19)	DOWN (27)	Ambient Temperature
04:10	12.48	6.56	81.87	-12.86	10.00	-
04:20	12.47	6.62	82.55	-13.33	10.00	-
04:30	12.46	6.60	82.24	-13.75	10.00	-
04:40	12.45	6.54	81.42	-14.13	10.00	-
04:50	12.44	6.59	81.98	-14.46	10.00	-
05:00	12.43	6.56	81.54	-14.82	11.00	28.70
05:10	12.42	6.50	80.73	-15.12	10.00	-
05:20	12.42	6.50	80.73	-15.40	11.00	-
05:30	12.40	5.69	70.56	-15.68	11.00	-
05:40	12.39	6.45	79.92	-15.82	12.00	-
05:50	12.38	6.47	80.10	-15.87	11.00	-
06:00	12.37	6.47	80.03	-15.87	11.00	28.70
Average Current consumption			6.57			
Average power consumption			82.69			

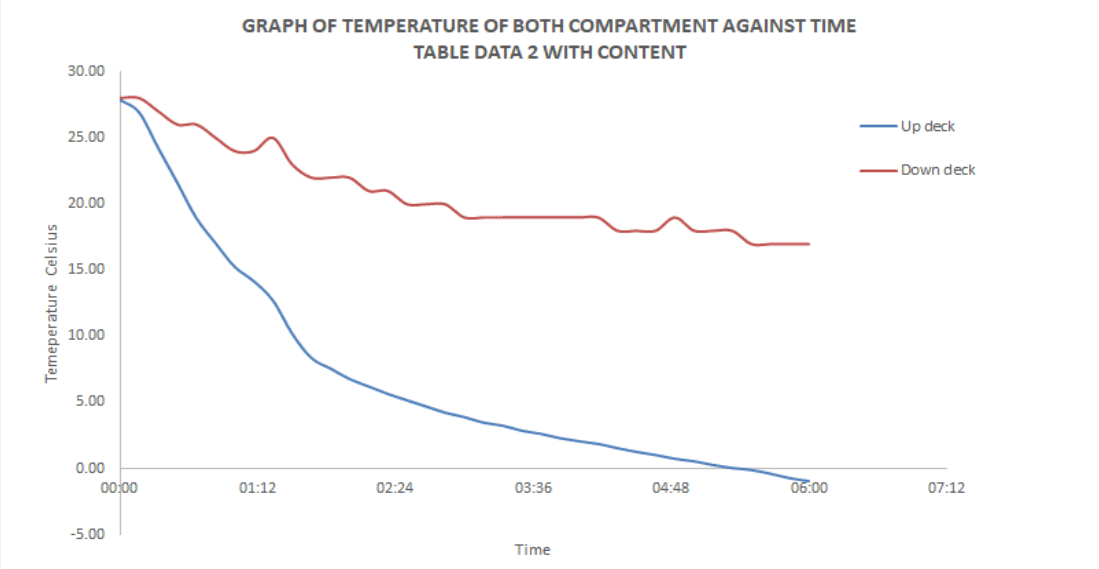
Table 8: Test data table 3

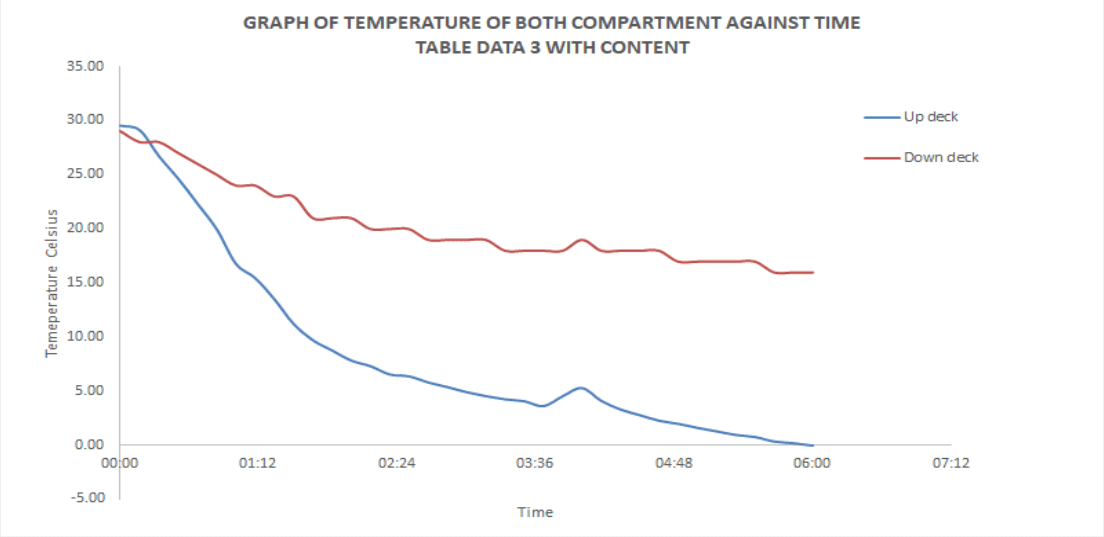
Time	V (13.42)	I	W	UP (27.52)	DOWN (27)	Ambient Temperature
00:00	13.00	9.00	117.00	27.20	27.00	25.20
00:10	12.82	6.35	81.41	24.74	26.00	-
00:20	12.85	6.36	81.73	21.92	25.00	-
00:30	12.78	6.53	83.45	18.34	24.00	-
00:40	12.74	6.78	86.38	14.72	22.00	-
00:50	12.68	6.96	88.25	11.92	21.00	-
01:00	12.70	7.12	90.42	7.85	19.00	26.30
01:10	12.68	6.96	88.25	5.77	18.00	-
01:20	12.67	7.02	88.94	2.48	16.00	-
01:30	12.64	7.06	89.24	0.13	14.00	-
01:40	12.64	6.93	87.60	-2.18	13.00	-
01:50	12.62	6.87	86.70	-3.78	12.00	-
02:00	12.61	7.00	88.27	-5.05	10.00	26.80
02:10	12.60	6.96	87.70	-5.95	10.00	-
02:20	12.58	6.95	87.43	-6.88	9.00	-
02:30	12.57	6.91	86.86	-8.01	8.00	-
02:40	12.56	6.83	85.78	-9.00	7.00	-
02:50	12.54	6.54	82.01	-9.85	7.00	-
03:00	12.53	6.74	84.45	-10.69	7.00	27.20
03:10	12.51	6.90	86.32	-11.51	7.00	-
03:20	12.50	6.74	84.25	-12.25	7.00	-
03:30	12.49	6.69	83.56	-12.91	7.00	-
03:40	12.48	6.65	82.99	-13.56	7.00	-
03:50	12.47	6.66	83.05	-14.13	7.00	-
04:00	12.46	6.70	83.48	-14.55	7.00	27.40
04:10	12.45	6.62	82.42	-15.12	8.00	-
04:20	12.44	5.63	70.04	-15.61	8.00	-
04:30	12.43	6.59	81.91	-15.87	8.00	-
04:40	12.42	6.57	81.60	-16.06	8.00	-

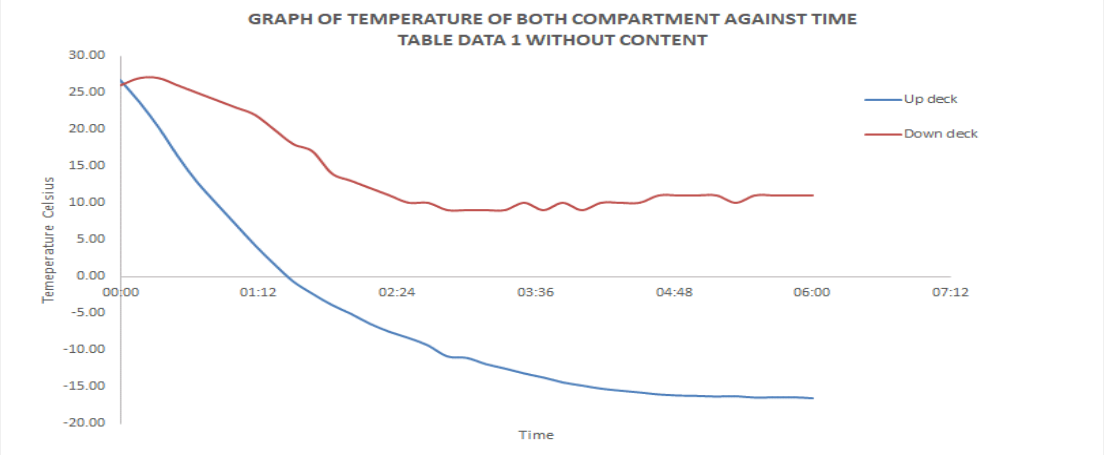
Time	V (13.42)	I	W	UP (27.52)	DOWN (27)	Ambient Temperature
04:50	12.41	6.53	81.04	-16.29	8.00	-
05:00	12.40	6.58	81.59	-16.39	9.00	28.30
05:10	12.39	6.64	82.27	-16.39	9.00	-
05:20	12.38	6.29	77.87	-16.53	8.00	-
05:30	12.38	6.60	81.71	-16.44	9.00	-
05:40	12.35	5.79	71.51	-16.58	9.00	-
05:50	12.35	6.37	78.67	-16.58	9.00	-
06:00	12.34	6.60	81.44	-16.58	8.00	27.90
Average Current consumption			6.73			
Average power consumption			84.53			

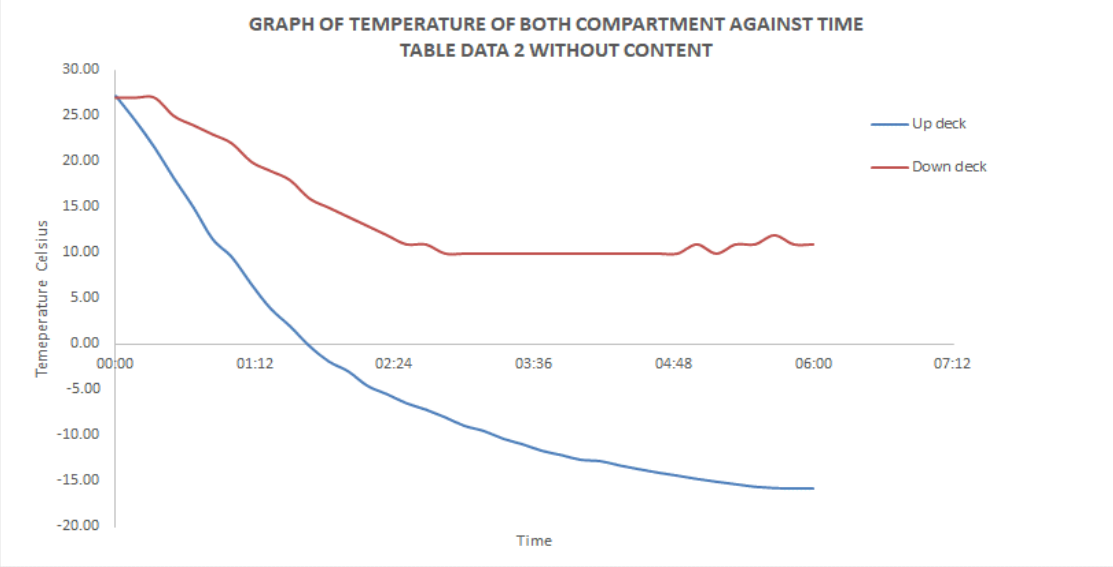
The graphical representation of the temperature against time for all tables of data in both scenarios (with and without content) are provided below:

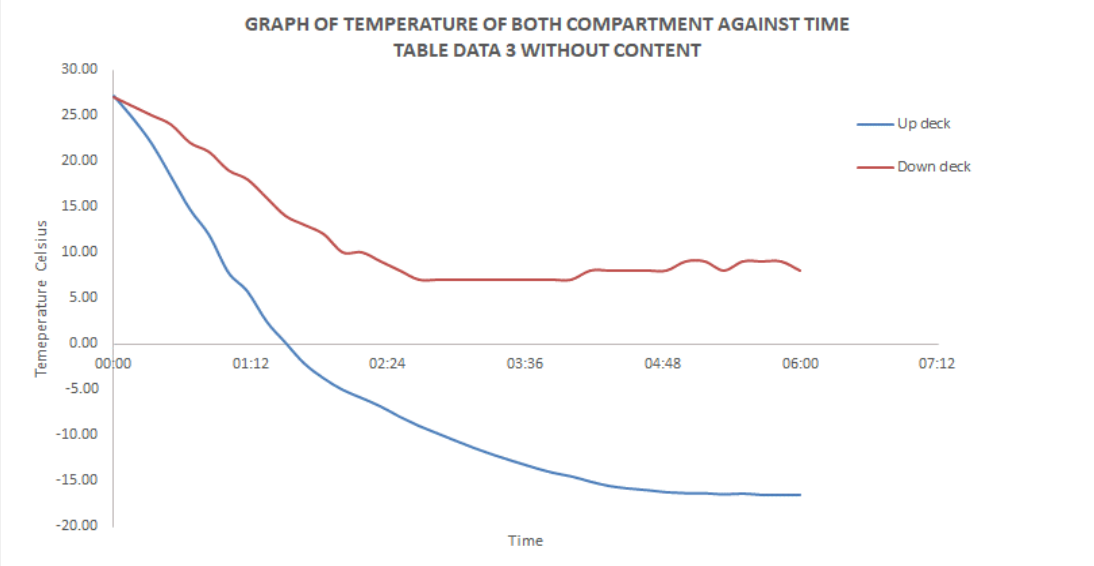





GRAPH OF TEMPERATURE OF BOTH COMPARTMENT AGAINST TIME
TABLE DATA 3 WITH CONTENT
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
Temeperature Celsius
00:00
01:12
02:24
03:36
04:48
06:00
07:12
Time
Up deck
Down deck


GRAPH OF TEMPERATURE OF BOTH COMPARTMENT AGAINST TIME
TABLE DATA 1 WITHOUT CONTENT
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
Temeperature Celsius
00:00
01:12
02:24
03:36
04:48
06:00
07:12
Time
Up deck
Down deck


GRAPH OF TEMPERATURE OF BOTH COMPARTMENT AGAINST TIME
TABLE DATA 2 WITHOUT CONTENT
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
Temeperature Celsius
00:00
01:12
02:24
03:36
04:48
06:00
07:12
Time
Up deck
Down deck



DISCUSSION

Following the test goals, the following observations were made, and we can address them one at a time.

The temperature is plotted against time in the graphic representation. This illustrates the relationship between the temperature insiderefrigerator compartment temperature and time. The graph displays the cooling curves for each compartment; as would be expected, the up deck has a cooler curve that is steeper than the down decks. It is evident that the up-deck cooling curve constantly exceeds the freezing threshold in the absence of content. The system performed admirably throughout a 6-hour period of operation using battery power. In fact, the battery could continue to run for several hours after the test because it was not completely depleted. This we can prove by the following calculations using the data extracted from the tables above.

$$\text{Battery life} = \frac{\text{Battery capacity}}{\text{Average current consumption of the entire system per test}}$$

With content

Table data 1:

$$\text{Battery life} = \frac{180\text{Ah}}{7.74\ \text{A}} = 23.3\ \text{Hours}$$

Table data 2:

$$\text{Battery life} = \frac{180\text{Ah}}{8.03\ \text{A}} = 22.4\ \text{Hours}$$

Table data 3:

$$\text{Battery life} = \frac{180\text{Ah}}{7.90\ \text{A}} = 22.8\ \text{Hours}$$

$$\text{With content the battery will last for ; } \frac{23.3 + 22.4 + 22.8}{3} = 22.8 \text{ hours}$$

Without content

Table data 1:

$$\text{Battery life} = \frac{180\text{Ah}}{6.96\ \text{A}} = 25.9 \text{ Hours}$$

Table data 2:

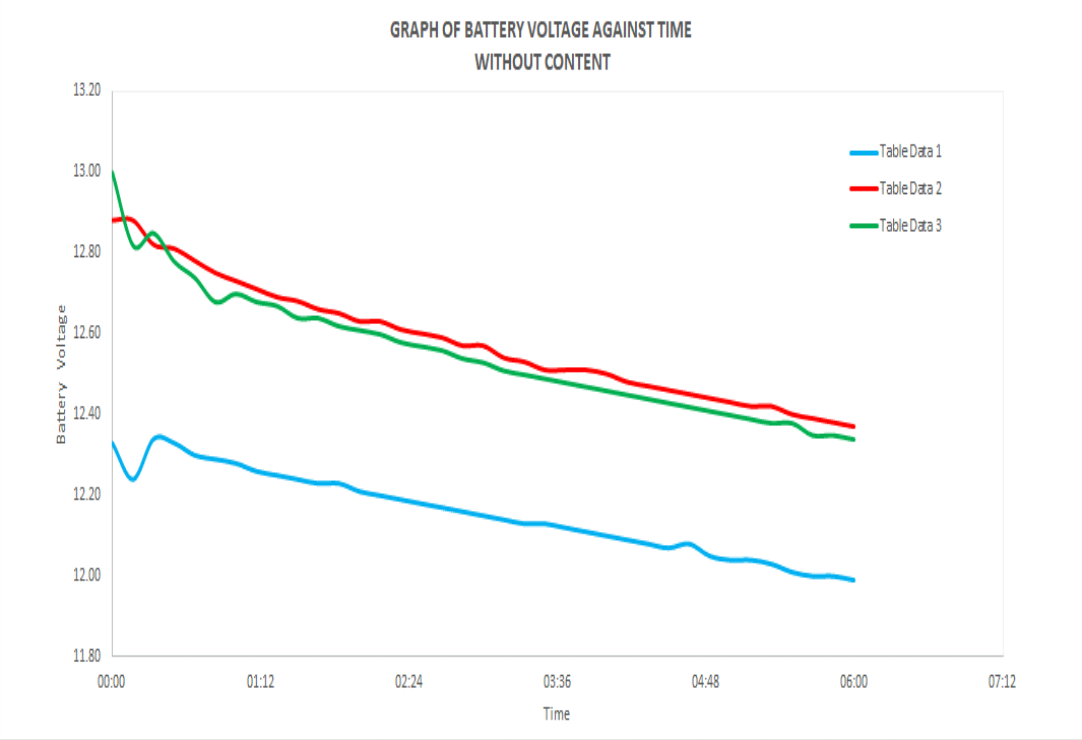
$$\text{Battery life} = \frac{180\text{Ah}}{6.57\ \text{A}} = 27.4 \text{ Hours}$$

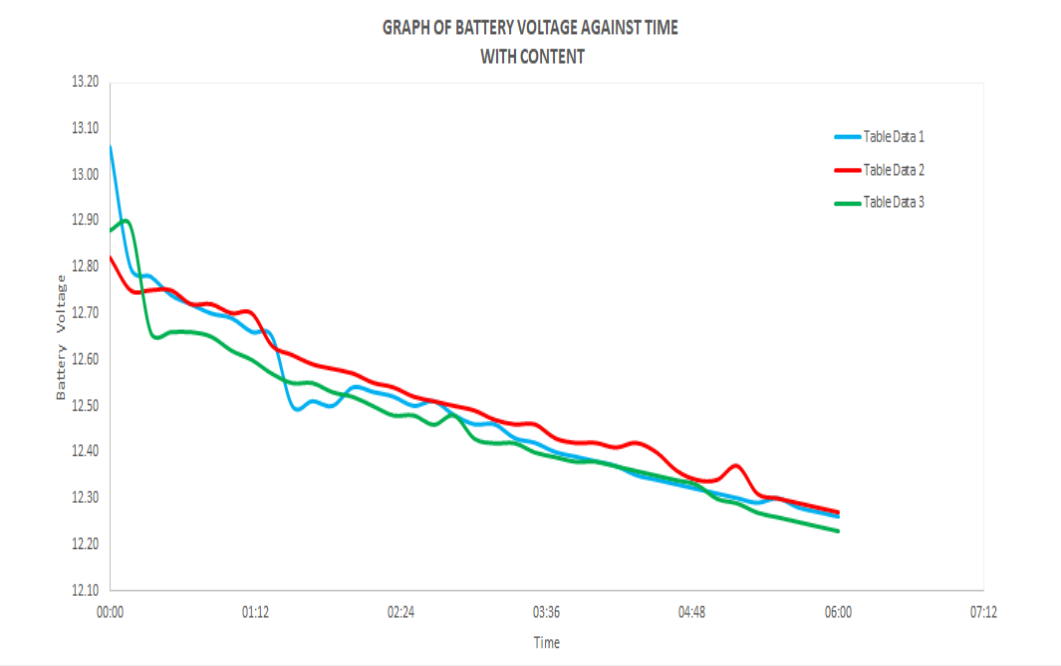
Table data 3:

$$\text{Battery life} = \frac{180\text{Ah}}{6.73\ \text{A}} = 26.7 \text{ Hours}$$

$$\text{Without content the battery will last for ; } \frac{25.9 + 27.4 + 26.7}{3} = 26.7 \text{ hours}$$

The computations unequivocally demonstrate that when the system is filled with contents, it demands more current, which led to a greater demand of power. In both scenarios, the battery will power the device for at least 20 hours.From the calculations above it can be seen that the DC storage will provide power to the system for approximately, 4 hours more when there are no content in the refrigerator.





The graph above shows the gradual fall of the battery voltage in both cases. In all cases the battery never falls below 12V.

According to the table of data, the up-deck's temperature falls below freezing point of 0^{O}C in 1:40 hours when nothing is in the refrigerator, but it will take longer than 5 hours for the temperature to fall below the 0°C barrier with content. The temperature curve is steeper when the contents are refrigerated.

The outcome demonstrates that adding contents to the system uses more energy. When there is no content, an average of 83.9 W is utilized, compared to 98.5 W with contents.

$$\text{Average power comsumed} = \frac{\text{Sum of mean power consumed in each test}}{3}$$

$$\text{Average power comsumed} = \frac{84.61 + 82.69 + 84.53}{3} = 83.9 \text{ W (without content)}$$

$$\text{Average power comsumed} = \frac{96.67 + 100.45 + 98.34}{3} = 98.5 \text{ W (with content)}$$

The energy delivered by the PV panel

$$E_{pv} = A \times r \times H \times PR$$

where:

E_{pv} is the energy output in kilowatt-hours (kWh)

A is the panel's area in square meters (m^2)

r is the panel's efficiency or yield in percentage (%)
H is the annual average solar radiation on tilted panels in kWh/m^2
PR is the performance ratio, a coefficient for losses ranging from 0.5 to 0.9
In view of the following parameters, the total energy supplied by the PV panel for 180mins for which the system was operated using solar energy was obtained.
A = 1.64m^2
r = 15.4%
H = 1361 kWh/m^2
PR = 0.75
$E_{pv} = 1.64 \times 0.154 \times 1361 \times 0.75 = 258\text{W}$

Power input to the compressor

$$W_{Compressor} = \frac{E_{PV}}{\Delta t}$$

where Δt (h) is the total time period over which the experiment is done and E_{PV} (Wh) is the total energy generated by the PV panel.
Using equation above, the power supplied to the compressor from the PV panel was obtained. The following parameters were used:
E_{PV}= 258 W
Δt = 6 hours

$$W_{Compressor} = \frac{258}{6} = 43\ W$$

Coefficient of performance of the system, COP is a measure of how efficiently it removes heat from the cold reservoir (inside the refrigerator) and transfers it to the hot reservoir (outside the refrigerator). This can be obtained using the expression below:

$$K_C = \frac{T_c}{T_H - T_C}$$

where:
T_H is the temperature of the environment to which the heat is dispelled to
T_C is the temperature of the space to cool off
K_C is the cooling coefficient of performance for a refrigerator or an air conditioner
The coefficient of performance for the refrigeration system is calculated using equation above. The COP with content in the refrigerator and the COP of the refrigerator without content.

COP with content experiment

The temperature of the hot reservoir (T_H) = 28.95°C = 302.1 K
The temperature of the cold reservoir; up deck (T_C) = -0.9°C = 272.3 K
The temperature of the cold reservoir; down deck (T_C) = 10°C = 283.2 K

Using the equation above, the COP was computed to be:
Up deck COP = 9.1; Down deck = 15

COP without content experiment

The temperature of the hot reservoir (T_H) = 27.47ºC = 300.6 K
The temperature of the cold reservoir; up deck (T_C) = -12.26ºC = 260.9 K
The temperature of the cold reservoir; down deck (T_C) = 16 ºC =289.2
Using the equation above, the COP was computed to be:
Up deck COP = 6.6; Down deck = 25.4
NB: temperature was converted to kelvin

CONCLUSION

In this work, a solar-powered refrigeration system with home and industrial applications has been designed. As long as solar energy is available to power the system, the refrigerator can be utilized to keep materials cool. The battery provides backup power to the system during the night. Experiments were conducted both with and without the presence of content in the refrigerator. In each experiment, the up-deck area was found to often cross the freezing point temperature without any substance. The down deck was designed to keep food products fresh, and the temperature reported during the test was within refrigeration temperature. In both instances, the temperature did not fall below 7 degrees Celsius.The 180mAH battery lasted more than 20 hours in both cases, with and without content. The COPs for both studies were determined to be: Up deck COP: 9.1; Down deck: 15 for the with content experiment and Up deck COP: 6.6; Down deck: 25.4 for the without content experiment.

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