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Design and implementation of solar powered mini refrigerator using thermoelectric cooler module

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Abstract. Remote areas are known for lack of conventional electrical power supply. But it is a common phenomenon to find health centres in remote areas, where vaccination campaigns are done regularly. Due to small populations, vaccines opened cannot be completely used and some usually get bad. The objective of this project is to design and implement a portable and energy efficient refrigerator for preservation of vaccines in medical centres found in remote areas where electric power supply is absent. The novelty of this work is on the use of planks, which are local materials and cheapfor the construction of the frame of the refrigerator.The experimental method is used, that helps to determine the functional operation of the system and the limit to which the system functions. The main component of the refrigerator is the thermoelectric cooler module tec1-12706.The system is tested under various conditions such as simultaneous use of PV module and storage battery as source of electrical energy. The absence of cooling fan on the hot side of tec1-12706.The results show that the temperature of the system reduces from 28^0 C to 5^0c within one hour of operation. And the temperature of the hot side of the tec1-12706 module increases drastically within 15 minutes of operation if there is an absence of fan on the hot side. With this the module is easily damaged. From the literature review,the COP is maximum0.6 but the present work raises the COP to 0.7.this is done by reducing the input energy. It is then recommended that the system should not be operated without a fan attached to the hot side of the tec1 module.

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1. Introduction

Solar powered mini refrigerators are portable refrigerators that are powered by solar power system. They use thermoelectric cooler module also known as Peltier element,as the main refrigeration component. Its principle of operation is based on the Peltier effect .which is a change in temperature at the junction between two dissimilar materials when electrical power is supply to it. the development of this refrigerator is based on the fact that it is pollution free as it does not use chlorofluorocarbon used by other types of refrigerators like the compression and absorption refrigerators.The fundamentals of the refrigeration phenomenon as used in this project are governed by the second law of thermodynamics. Which is expressed in two laws as; Clausius statement of second law of thermodynamics: “It is impossible to have a device that while operating in a cycle produces no effect other than transfer of heat from a body at low temperature to a body at higher temperature.” [1]and Kelvin-Planck statement of second law of thermodynamics: “It is impossible for a device operating in a cycle to produce net work while exchanging heat with bodies at single fixed temperature”. [1].the main objective of this work, is to provide medical centers in remote areas with a reliable and energy efficient refrigerator for their vaccines..

1.1 Significance of the project

The solar thermoelectric refrigerator:
- Saves electrical power.
- It is a portable device.It can be very useful in far off remote places where there is no supply of grid electricity
- It is eco-friendly. The system reduces greenhouse gas emission as it does not produce hazardous gases like carbon dioxide.
.- It is an energy efficient device. .
- It uses a clean energy source.
- Its use ultimately reduces the harmful effects which are caused by refrigerants in absorption refrigerators and compression refrigerators.

2. Literature review

Jean Peltier discovered that when an electrical current is applied across the junction of two dissimilar metals, heat is removed from one of the metals and transferred to the other [2]. This is the basis of thermoelectric refrigeration. In short, when current is passed through a circuit, one junction increases in temperature while the other junction cools down

An experimental and numerical study of the thermoelectric air cooling and air heating system was presented by Mathieu Cosmier et al in 2008 [3],where they said they have reached a cooling power of 50W per module with a coefficient of performance (COP), between 1.5 and 6.0 by supplying an electrical intensity of 4A. And maintained the 5^0 C temperature difference between hot and cold sides.

3. Materials and Methods

3.1 Materials

The following materials were used to realize this project: The cooling load,Thermoelectric cooler **(Peltier)** module, Heat sinks, The fans, The PV module, The charge controller,The battery**,** Digital, thermometer, Polyfoam, Plastic, Cables, Switches,Circuit breaker.

3.2 Method.

The research method used in this project is the experimental method and secondary sources.
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Fig.1. refrigerator showing its cooling chamber

The design for the experimental system is described below.

The cooling chamber is designed to a size of 20cm in length, 15cm in width and 20cm in height. This provides a 6 liters cooling space. The outside walls are made of plank material while the walls of the cooling chamber are made of plastics. This enables the temperature of the chamber to be uniform. Separating the outside and inside wall is a polyfoam insulated material to prevent external heat from entering the refrigerator so that the refrigeration process should not be affected. Below the cooling chamber is a space designed to house the battery and the charge controller. The door which is made of the same materials as the walls of the refrigerator also has rubber bands at the terminals. This enables it to have solid contact with refrigerator wall to which it is in contact. The rubber bands also seal the air spaces and prevent the ambient air or heat from entering the cooling chamber. The joints of all the walls are sealed with 99durabond to prevent the transfer of heat through any undesired hole. At the back of the cooling chamber is a hole to the size of the Peltier module, in which the Peltier module is placed, linking the cooling chamber and the surrounding. On the cooling chamber side of the Peltier module is a small heat sink attached to a fan. The fan circulates the cold air inside the cooling chamber. The hot side of the module, which is outside of the cooling chamber, is connected also to a heat sink bigger than that inside. The Peltier module is connected to the

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internal and external heat sinks, through thermal paste, which is a silver-grey substance that allows for efficient transfer of heat between the Peltier module and the heat sinks, for it creates a complete contact between the Peltier module and the heat sinks. The outside heat sink that conveys heat from the hot side of the module to the environment is also connected to a 12V, 0.26A DC fan, to reduce the temperature of the heat sink. This is to ensure the Peltier module effectively removes the heat from the cooling chamber to the surrounding. The back is covered with iron net to protect the fan and heat sink

The Peltier module is electrically connected to the battery and charge controller using cables. At the back of the refrigerator, there are two hubs for connecting a 17.9V solar module to the PWM charge controller. A toggle switch is also provided at the back, to either connect or disconnect the system from the supply.

Inside the chamber is a 12V LED lamp to indicate the system is powered. It is also used to make the content of the refrigerator visible at night.The solar panel is connected to the hubs with a long cable to permit it trap sunlight some distance away from the refrigerator when charging the battery or operating the system. the digital thermometer is passed through a very tiny hole into the cooling chamber and attached to the body of the refrigerator using clips. The temperature is read every minute to check the temperature changes in the cooling chamber. Under test conditions the thermometer is read for one hour.

3.2.1 Functioning of the system

The solar powered mini refrigerator using thermoelectric cooler module works on the principle of conversion of solar energy into electrical energy and operates on the concept of Peltier effect, where when current is applied to the Peltier module it produces a cooling effect.

The solar panel traps radiation from the sun and the irradiation is converted to electrical energy by the PV cells of the solar panel. The solar panel then produces a voltage. When the panel is connected to the charge controller, the charge controller with a DC-DC converter reduces the voltage to 12V.the charge controller which in turn is connected to the battery, causes current to begin to flow to the battery. This current flows in the form of movement of charges which carry electrical energy, which then charge the battery. The charge controller controls the charging and discharging of the battery so that it should not be over charged nor over discharged. When the battery is fully charged, the solar panel may be disconnected by the charge controller. During the day the solar panel is left connected while the system works. Part of its energy is used for running the system and part is used to charge the battery. In this case the refrigerator obtains its power directly from the solar panel and battery through the charge controller. At night the solar panel does not produce any electrical energy as such the refrigerator works solely on the battery. The battery supplies power to both the Peltier module, the LED lamp and the two fans.

To put ON the system, the toggle switch S1 is used to put on the Peltier module while the appliance control switch on the charge controller at the back of the refrigerator is pressed ON, voltage appears across the electrical components and current then starts to flow to the Peltier module, the two fans and the LED lamp. They simultaneously start to function. The lamp comes on, the fans start to rotate and the Peltier module starts pulling heat from the cooling chamber and pumping it to the outside environment through the heat sink. While the inner side gets colder, the outer side of the module gets hotter. The heat sink then conveys the heat to the surrounding. To avoid damaging the Peltier module as it produces heat on the outside, the fan blows the heat sink so that the outside temperature of the module is greatly reduced. This facilitates the module to remove more heat from the cooling chamber and work continuously without being damaged. As the temperature around the Peltier module in the cooling chamber starts to reduce. The rotation of the fan circulates the air in the cooling chamber, making the temperature of the chamber uniform. The system is stopped by pressing the toggle switch again off.

Calculations

The general equation for heat transfer

Q=UAΔT. (1)

Q= total heat transfer

U=overall heat transfer coefficient,

A = area of transfer surface,

ΔT=temperature difference between initial room temperature 25^0C and final temperature of cooled substance 5^0C.

The heat transfer balance equation for the thermoelectric cooler becomes

Qh = Qc + W [4] (2)

For passive load:

$Q_{thermoco}l = h\Delta T/L$(3)

Fouriers law for heat transfer from flat surfaces [5]

Thermal resistivity of Thermocool (rϴ) = 0.047w/mk

This implies thermal coefficient of Thermocool

(h) =1/ rϴ

Length of Thermocool = 0.2m

ΔT=200C

=293K

$Q_{thermocol}$ = (293)/(0.047 x 0.2) =31170.21 Considering the time to cool the water is 1 hour = 3600s

$Q_{thermocol}$ as power for 1 hour 31170/3600 =8.66W

$Q_{rubber} = h\Delta T/L$

Thermal resistivity of rubber rϴ = 0.014w/mk

Length of rubber = 0.2m

ΔT = 200C=293 K

Q_{rubber}= 293/(0.014 x 0.7) = 29897.96

Q_{rubber} as power for 1 hour =29897.96/3600 =8.3W

For convection of air

Qair = h ΔT

But h=kNu/L for convection at flat surface [5]

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$Q_{air} = kNu\,\Delta T/L$ (4)

$Nu = 0.664Re^{1/2}Pr^{1/3}$ for air

$Pr = 5/7 = 0.71$

$K_{air} = 0.02435$ W/mk thermal resistivity of air

$Re = U\infty L/v$

Speed of air ($U\infty$) = 10m/s

Length of chamber (L) =0.2m

Kinetic viscosity of air at 25 0C (v) =14.6x10-6

Re = (10x0.2)/ 14.6x10-6 =136986

Nu =0.664(1369861/2) (0.71 1/3) = 218.73

$Q_{air} = kNu\Delta T/L$

= 0.02435x218.73x293/0.2

= 1560.51J

= 1560.51/3600 =0.43W

Qpassive= Qthermocol + Qrubber + Qair

= 8.66 +8.3 + 0.43 =17.4W

For active 'load Q

$Q_{active} = MC_p\Delta T/t$ (5)

where t = 1hour =3600s time to cool the water.

Considering 1 liter of water as test substance to be cooled

Mass of water (m) = 1kg

Specific heat capacity of water at constant pressure (c_p) = 4180 J/kgK

$\Delta T = 20^0C$

Q_{active} = 1(4180)(20) =83600J

=83600/3600 =23.2W

total cooling load $Q_c = Q_{passive} + Q_{active}$

Q_c = 17.4 + 23.2

=40.6W

4. Performance analysis of the refrigerator

The following graphs have been obtained due to the results shown by reading the temperature of the cooling chamber using digital thermometer over a period of 60minutes.

4.1. Effect on temperature of cooling chamber due to absence of PV module

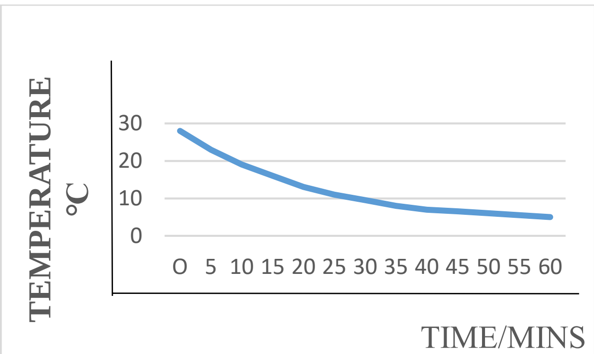


Fig 2. Effect on temperature of cooling chamber due to absence of PV module

The figure shows the variation of temperature of the cooling chamber with respect to time. The curve shows that the temperature of the cooling chamber reaches 5^0C after 60 minutes of operation, when the PV module is not in used but the battery only

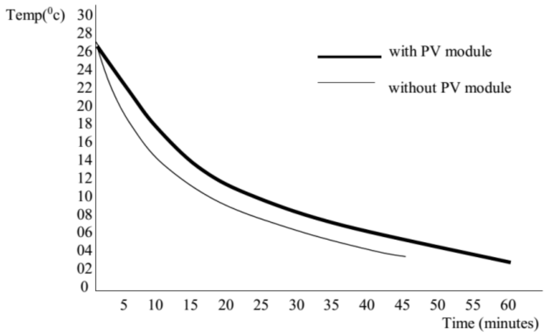
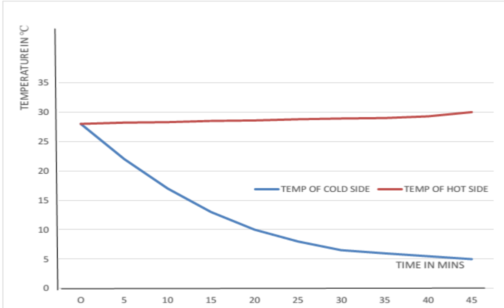


Fig.3. Effect of PV module on the temperature of the cooling chamber

The figure shows the variation of temperature against time when both the solar battery and PV module areused together. Here the temperature of cooling chamber reaches 5^0C within 45minutes of operation.



.Fig.4. Variation of temperature on the hot side and cold side of the thermoelectric refrigerator with fans on both sides

This figure shows the temperature variation on both the hot side and cool side of the thermoelectric module when cooling fans are used on both sides. Here the temperature of the hot side increase very slightly while that of the cold side decreases exponentially over a period of 60minutes.

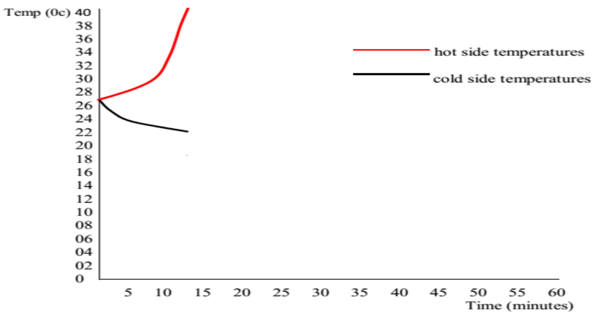


Fig.5. Variation of temperature on the hot side and cold side of refrigeratorwithout a fan on the hot side.

The figure shows the variation of temperature on both the hot and cold sides of the module when there are no cooling fans. Here the temperature of the hot side increases drastically within 15minutes to 40^0c.which can damage the module.

5. Conclusionand recommendation.

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The thermoelectric refrigerator functions best when the photovoltaic (PV) module and the solar battery are put together as the source of energy. The fast rise in the temperature of the hot side of the thermoelectric module is a clear indication that without the fan on the hot side of the refrigerator, the system may not function for 20 minutes, without damaging the Tec1-12706 module.it is recommended that the system should not be operated without the fan on the hot side

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