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DESIGN AND FABRICATION OF THERMOELECTRIC REFRIGERATOR

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ABSTRACT
The impact of on-going progress in science and technology has created a variety of system that can be used in producing the refrigerator effect with the use of thermoelectric cooling which is also known as the Peltier heat pump, solid state refrigerator. It can be used either for heating or for cooling; although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cool. It has the advantage of having no moving parts and thus it needs little or no maintenance. Thermoelectric refrigeration is a new alternative cooling device since the problem of compression is taken care off by it. This paper presents the details design and fabrication of a Thermoelectric refrigerator with 12 Peltier modules, 5 12V DC fans, a fridge and freezer compartment. The thermoelectric refrigerator's operating power is sourced from an Alternating Current power outlet; an applied electrical power of 57 W was used. The Peltier modules were used to cool the compartments of the refrigerator. The approach intended to exploit the Peltier effect with the use of Peltier modules, to generate a cooling effect in the refrigerator compartments. From the data collected during performance evaluation, we analyzed the coefficient of performance of the Peltier Modules used to be 81.85 % and the thermoelectric refrigerator's fridge and freezer compartments were able to achieve temperatures of 6.9 ℃ and −5.3 ℃ respectively after 2 hours of usage while being loaded.

KEYWORDS: Refrigerator, Peltier Module, Freezer, Fridge

1.0 INTRODUCTION

1.1 Thermoelectric Refrigeration

Thermoelectric refrigeration is a type of cooling technology that uses the thermoelectric effect to transfer heat from one side of a device to the other. It is a solid-state technology that does not use any moving parts or refrigerants, making it a potentially more reliable and efficient alternative to traditional refrigeration systems that rely on mechanical compressors [1]. The thermoelectric effect refers to the ability of certain materials to generate a voltage when there is a temperature difference between the two sides of the material. In a thermoelectric refrigeration system, this voltage is used to drive an electric current through a pair of thermoelectric modules, which are made up of p-type and n-type semiconductor materials. The p-type material has an excess of holes (positive charge carriers) and the n-type material has an excess of electrons (negative charge carriers) [2]. When an electric current is applied, the holes and electrons migrate towards the cold side of the module, creating a temperature difference across the module. This temperature difference causes heat to be transferred from the hot side of the module to the cold side, effectively cooling the hot side. Thermoelectric refrigeration systems can be used for a variety of applications, including cooling electronic devices, preserving food and medication, and air conditioning. They have the potential to be more energy efficient than traditional refrigeration systems, particularly in small-scale applications where the cooling load is relatively low. However, they are not as effective at cooling large spaces or removing moisture from the air, and are generally more expensive to install and maintain. Figure 1.0 shows, a Peltier circuit configured as a thermoelectric cooler.[3]

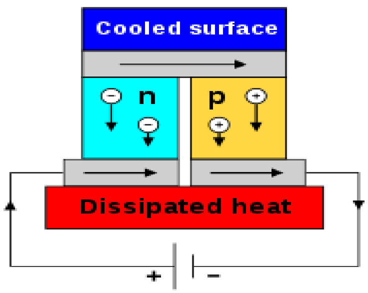

Figure 1: The Peltier circuit configured as a thermoelectric cooler

2.0 THEORY

2.1 Design and Characteristics of the Peltier Module

The Peltier module comprises of two unique semiconductors, one n-type and one p-type, which are used because they need to have different electron densities. The alternating p & n-type semiconductor pillars are thermally placed in parallel to each other and electrically in series and then joined with a thermally conducting plate on each side.[4] When a voltage is applied to the free ends of the two semiconductors there is a flow of DC current across the junction of the semiconductors, causing a temperature difference. The side with the cooling plate absorbs heat which is then transported by the semiconductor to the other side of the device. A good majority of thermoelectric coolers have an ID printed on the cold side. These universal IDs clearly indicate; The size, Number of stages, Number of couples, Current rating in amps; [5]

Figure 2 shows how to identify the characteristics of Peltier module through the ID numbers on the cold sides

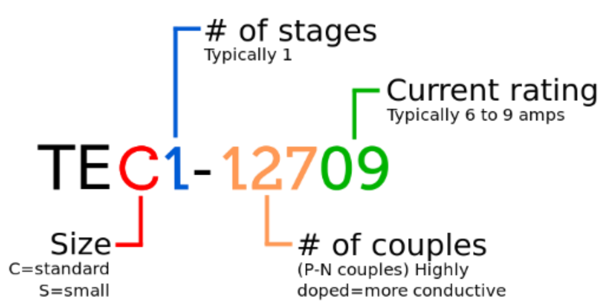

Figure 2: ID numbers on the cold side of a Peltier module [6]

2.2 Performance of Thermoelectric Cooling

A Peltier (thermoelectric) performance is a function of ambient temperature, thermal load, Peltier module (thermopile) geometry, as well as hot and cold side heat exchanger (heat sink) performance, and Peltier electrical parameters.

The amount of heat that can be moved is proportional to the current and time.

$Q = PIt$, where P is the Peltier coefficient, I am the current, and t is the time. The Peltier coefficient depends on temperature and the materials the cooler is made of. Magnitude of 10 watt per ampere are common, but this is offset by two phenomena:

1. Firstly, according to Ohm's law, A Peltier module produces waste heat itself,

$Q_{waste} = RI^2t$, where R is the resistance.

2. Heat will also move from the hot side to the cool side through thermal conduction inside the module itself, which is an effect that grows stronger as the temperature difference grows.

Hence, the result is that the heat effectively moved drops as the temperature difference grows, and the module becomes less efficient. A temperature difference occurs when the waste heat and heat moving back overcomes the moved heat, and the module starts to heat the cool side instead of cooling it further. In a single thermoelectric cooler this will produce a maximal temperature difference of 70 °C between its hot and cold sides.[7]

3.0 DESIGN AND MATERIALS

3.1 Material Selection

The material selected for the design and fabrication of the thermoelectric refrigerator were selected based on the following properties; strength, cost, corrosion resistance, availability of material, economy of repairs and maintenance, effectiveness and operational safety.

3.2 Materials Used

The following materials were used in this research; Fiber glass, 1.5mm aluminium sheet metal, 2.5mm aluminium sheet metal, Aluminium Heat sink, 12v dc fan, Rocker on/off switch, DC 12v temperature thermostat, Feet pads, Bolts and nuts, riveting pins, Peltier module, Transformer, Bridge rectifier glass passivated.

3.3 Design Consideration

Before designing the thermoelectric refrigerator, the following factors were considered; The durability of the materials used was taken into consideration, and the availability of the materials needed for the design and necessary tools to ensure the work is carried out without unnecessary interruptions.

3.4 Conceptual Designs

Three concepts for the design of the machine were considered, and based on specific criteria, the most viable concept was selected. The selection criteria put into consideration was based on the results from the decision matrix table.

CONCEPT 1

This concept was considered as a Mini-Peltier operated refrigerator, it consists of a direct current fan, and a heat sink, to dissipate heat, and two Peltier modules, and it also made use of polystyrene sheet for insulation which was expensive for purchase due to scarcity, it offered a cooling surface volume of 5,907.825 cm^3, hence, it had limited cooling volume. It made use of balsa wood, which was not as durable, as it would cause defect after a while due to the condensation, it produced the least cooling effect and had the lowest efficiency. Figure 3 shows the first conceptual design for the thermoelectric refrigerator

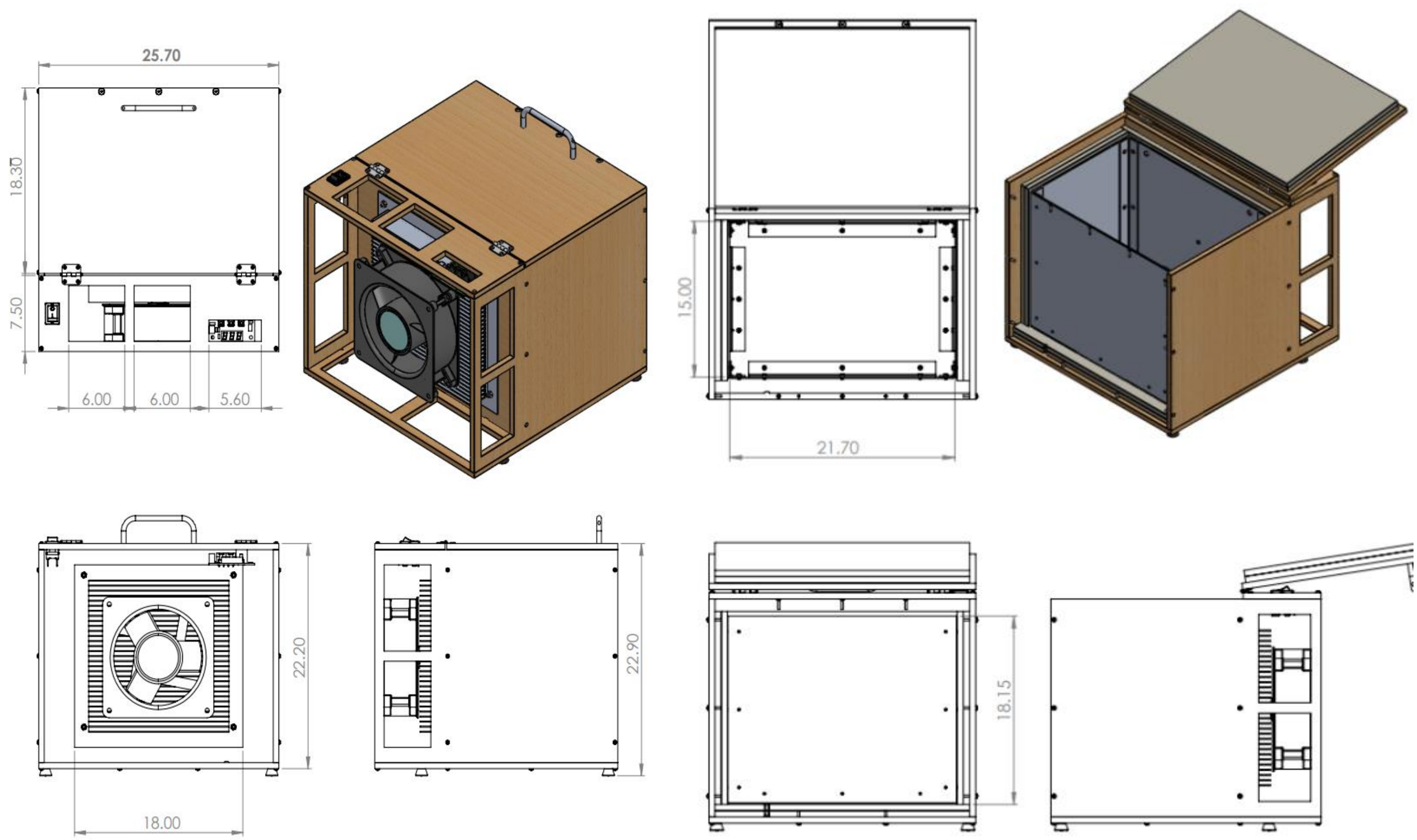

Figure 3: The first conceptual design for the thermoelectric refrigerator.

CONCEPT 2

This concept consisted of two compartments a fridge and a freezer two direct current fans, and two a heat sinks, to dissipate heat, and Four Peltier modules, to provide the cooling effect, and made use of a polystyrene sheet for insulation, it offered a cooling volume of 12.493 cm^3 for the fridge compartment and cooling volume of 24,986 cm^3.It also consist of two thermos readers to measure the temperature of the two compartments. Figure 4 shows the second conceptual design for the thermoelectric refrigerator. Similar, to concept 1 it made use of polystyrene foam and balsa wood which was expensive and less-durable, respectively.

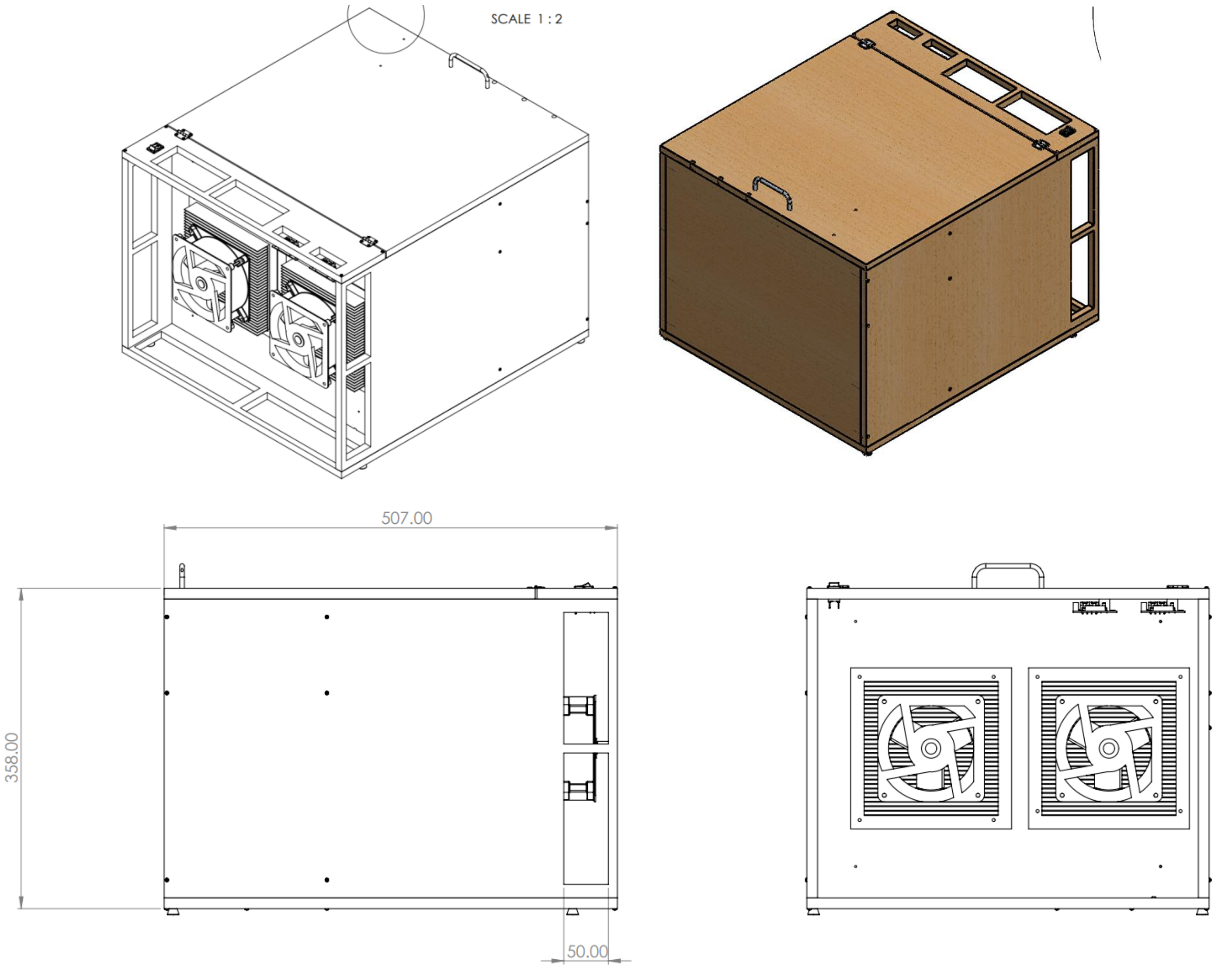

Figure 4: The second conceptual design for the thermoelectric refrigerator.

CONCEPT 3

This concept consists of two compartments a fridge and a freezer five direct current fans, along with five heat sinks needed to dissipate heat, it makes use of ten Peltier modules, to provide the cooling effect, and made use of a Fiber glass sheet glass material for insulation, which was less expensive, it offers a cooling volume of 86,567.8 cm^3 for the fridge compartment and cooling volume of 57,443.4 cm^3 .It also consist of two digital thermal readers to measure the temperature of the two compartments, It has a larger cooling volume and relatively more efficient. However, the overall manufacturing cost of the system was increased, in order to achieve a higher cooling effect, individually. Figure 4 shows the third conceptual design for the thermoelectric refrigerator.

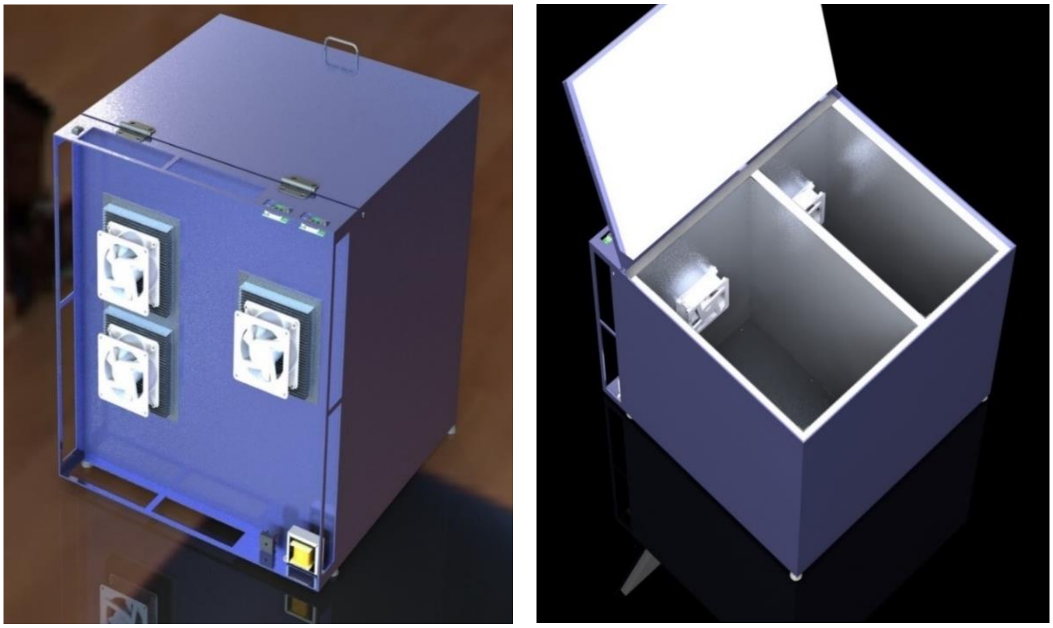

Figure 4: The third conceptual design for the thermoelectric refrigerator.

3.5 Evaluation and selection of concept using decision matrix

The most viable concept amongst the three concepts considered is selected using a decision matrix. Table 1 shows the decision matrix.

Table 1: The Decision matrix.

		CONCEPT 1		**CONCEPT 2**		**CONCEPT 3**	
DESIGN SPECIFICATION	WEIGHTING FACTOR	RATING	SCORE	RATING	SCORE	RATING	SCORE
COST	2	10	20	9	18	8	16
WEIGHT	2	8	16	7	14	8	16
SIZE	1	4	4	6	6	8	8
MAINTENANCE	1	5	5	6	6	7	7
EASE OF APPLICATION	2	5	10	9	18	9	18
RELIABILITY	2	5	10	7	14	9	18
TOTAL			65		76		83

*Score = Rating x Weighting Factor

From table 1, it is observed that Concept 3 has the highest weighted score based on the criteria considered, hence Concept 3 was adopted.

3.6 Design

3.6.1 Volume of the thermoelectric refrigerator

Volume of thermoelectric refrigerator = Length x breadth x height

Length = 610mm, Breadth = 610mm, Height = 610mm

Hence, volume of thermoelectric refrigerator = 610 x 610 x 610 = 226981000mm^3

The thermoelectric refrigerator has a standing height of 630mm

Thickness of the aluminium composite sheet used = 1.5mm

Thickness of the aluminium sheet = 1.5mm

3.6.2 Design of the thermoelectric refrigerator casing

The figure below showcases the thermoelectric refrigerator without some features attached.

The top part was designed with allowances to accommodate the on/off rocker switch, and the two thermostat readers to be placed on the top of the Peltier module.

Area = length x breadth

Area of on/off rocker switch = 21 x 15 = 315 mm^2

Area of Thermostat reader = 21 x 56 = 1176 mm^2

The top lid was designed to accommodate the two butt hinges to be used.

The back part was designed to accommodate the Peltier modules and aluminium bricks used.

Table 2 shows the performance specification for the thermoelectric refrigerator

Table 2: Performance specification for the thermoelectric refrigerator

T_H (ºC)	50ºC
$Qmax$ (Watts)	57W
$\Delta Tmax$ (ºC)	75
$Imax$(Amps)	6.4 amps
$Vmax$ (Volts)	16.4 V
Module Resistance (Ohms)	1.98 ohms
Seebeck coefficient	53x10^{-3}
Area of thermoelectric element	17.64cm^2
Length (G)	4.2cm
Breadth	4.2cm

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Mass	0.33 kg

The Peltier module used was a TEC1-12706;

3.6.3 Heat absorbed by the Peltier Module

The heat absorbed by the Peltier module was determined using equation (1)

$Q_c = S_m T_c I - \frac{1}{2} I^2 R_m - k_m \Delta T$ (1) [8]

I = Current (A) = 6.4 amps

T_a = Ambient Temperature (K) = 25 + 273.15 = 298.15 k

T_h = Hot side Temperature (K) = 50 + 273.15 = 323.5 k

T_c = Cold Side Temperature (K) = ΔTmax - T_h (2)

= 75 – 50 = -25+273.5 = 248.15 k

ΔTmax = Temperature change (k) = 75 = 75 + 273.15 = 348 .15k

V = Voltage (V) = 16.4V

Q_c = Heat absorbed at cold surface (W)

Q_p = Power input for TEC (W) = VI (3)

Q_p= 16.4 x 6.4 = 104.96W

S = Seebeck Coefficient = 53 x 10^{-3}V

k = Thermal Conductivity of the material used in bismuth telluride used in the Peltier module used made use of bismuth telluride thermal conductivity = 1.20x10^{-3} w/mm. k [9]

N = Number of pair of thermoelectric elements = 12 pairs

R = Resistance of the Peltier module = 1.98ohms

S_M = Device Seebeck Voltage

$S_M = \frac{v_{max}}{T_h}$ (4)

S_M = 16.4/323.15

S_M= 0.0495 v/k

k_M = Device Electrical Resistance

$k_M = \frac{(T_h - Tmax)V_{max}I_{max}}{2T\Delta Tmax}$ (5)

k_M = ((323.15 - 348.15) x 16.4 x 6.4) / (2 x 323.15 x 348.15)

k_M = -0.0116 w/k

R_M = Device Thermal Conductance = $\frac{(T_h - \Delta T_{max})v_{max}}{T_h . I_{max}}$ (6)

= ((323.15 - 348.15) x 16.4)/ (323.15 x 348.15)

= -0.1982 ohms

From Equation 1

$Q_c = S_m T_c I - \frac{1}{2} I^2 R_m - k_m \Delta T$

Q_c = (0.0507 x 248.15 x 6.4) – (0.5 x 6.4^2 x -0.1982) – (-0.0116 x 348.15)

Q_c = 85.91 W

3.6.4 Heat generated at hot side of the Peltier module

$Q_H = Q_c + Q_P$ (7)

85.91 + 104.96 = 190.8775 W

3.6.5 Coefficient of performance of Peltier modules

COP_{ref} = Coefficient of Performance = Q_c/Q_P (8) [8]

COP_{ref} = 85.95/104.96 = 81.85%

3.6.6 Heat sinks thermal resistance

$R_{heat\ sink} = \frac{T_h - T_a}{Q_c - Q_p}$ (9) [8]

$R_{heat\ sink}$ = (323.15-298.15) / (88.617+104.96)

$R_{heat\ sink}$ = 0.129 ohms

3.7 Design of Peltier Module

Figure 5: shows the design of the Peltier module assembly.

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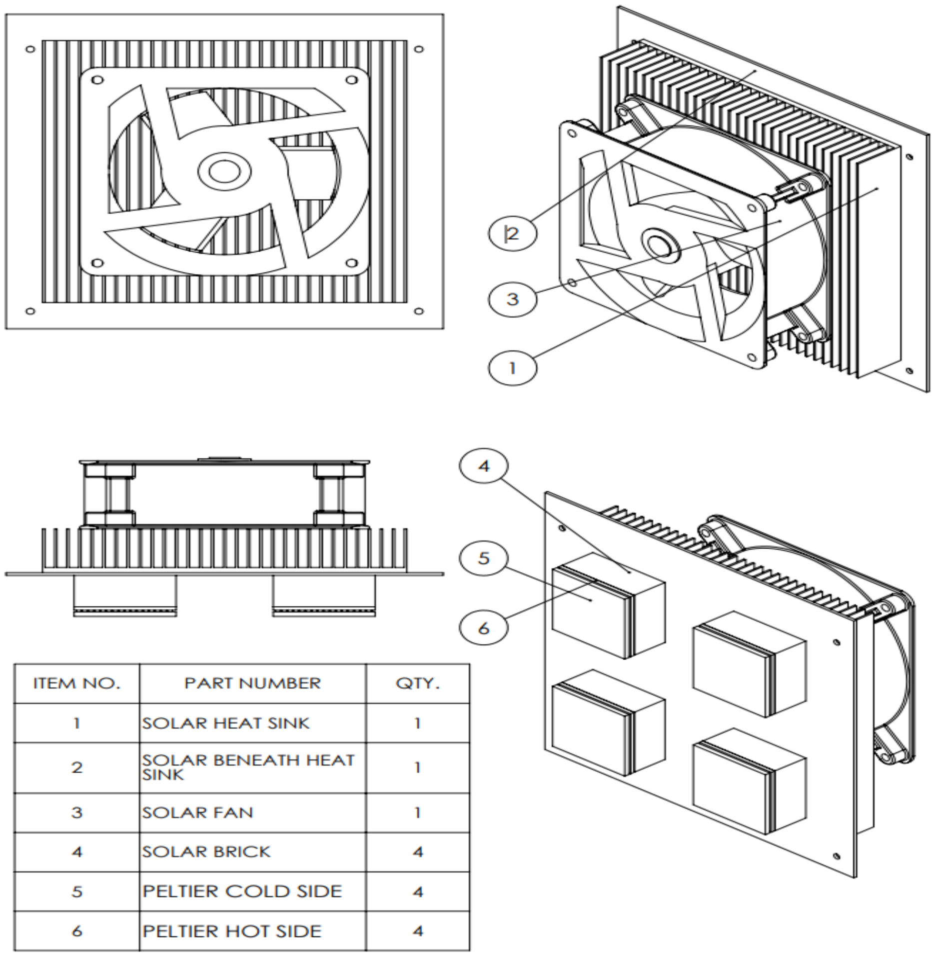

ITEM NO.	PART NUMBER	QTY.
1	SOLAR HEAT SINK	1
2	SOLAR BENEATH HEAT SINK	1
3	SOLAR FAN	1
4	SOLAR BRICK	4
5	PELTIER COLD SIDE	4
6	PELTIER HOT SIDE	4

Figure 5: The design of the Peltier module assembly

3.7.1 Design of cooling surface compartment (fridge)

The design below shows the design of cooling surface for the fridge compartment.

Volume = Length x Breadth x Height

Volume = 214mm x 473mm x 567.5mm = 57443485 mm^3.

3.7.2 Design of cooling surface compartment (freezer)

The design below shows the design of cooling surface for the freezer compartment.

Volume = Length x Breadth x Height

Volume = 325mm x 473mm x 567.5mm = 87238937.5 mm^3.

4. RESULTS AND DISCUSSION

4.1 Performance Evaluation

The readings from the refrigerator's compartments were taken 4 times, at 30 minutes intervals, with load (food items). We filled up three-quarter of the internal space of both compartments of the refrigerator, in order to allow the refrigerator, operate at maximum efficiency and ensure that air circulation is unhindered. The temperatures of both compartments were taken with the aid of the two digital thermostats, provided in the refrigerator. The thermostat sensor's tip was placed close to the doors in each of the fridge and freezer compartments respectively. Table 3 shows the readings gotten from the thermoelectric refrigerator's digital thermostat and a multimeter when loaded.

Table 3: The readings gotten from the thermoelectric refrigerator's digital thermostat when loaded.

S/N	Current (A)	T_{fridge} (℃)	$T_{freezer}$ (℃)	Time (Hr)
1	6.0	21.7	10.0	0.5
2	6.0	18.5	7.0	1.0
3	6.0	10.2	-0.1	1.5
4	6.0	6.9	-5.3	2.0

4.2 Working Principle of The Peltier Module

The thermoelectric refrigerator is powered through AC. The refrigerator makes use of a rocker switch to turn the refrigerator on. The thermoelectric refrigerator makes use of a stepdown transformer, which is used to step down the voltage entering into the machine. The normal voltage in most domestic households is 220v, hence the need for a step-down transformer to step down the alternating current to 12v, because the 6amps Peltier module runs on 12v current, the stepped down 12v current is passed to a rectifier which is used to convert the AC to DC, which would be supplied to the Peltier module.

The Peltier module; when direct current is passed through it; one side of the Peltier module is cooled and the other side heated up due to the Peltier effect. The cold side is in contact with the cooling surface of the respective compartment Fridge or freezer, In between the Peltier module and the cooling surface; thermal paste is applied to prevent heat loss by convection. In the internal part a blower is used per compartment to conduct cool air.

On the other side, of the Peltier module is a heat dissipating assembly that consists of the heat sink and 12v DC fans; This assembly is used to dissipate heat generated by the Peltier module to increase the effectiveness of the Peltier module, in between all connections thermal paste is used.

5. CONCLUSION

The design and fabrication of a thermoelectric refrigerator was successful as demonstrated by its ability to achieve cooling in various durations. The fridge and freezer compartments were able to reach temperatures of 6.9°C and -5.3°C respectively after 2 hours of usage. This shows the effectiveness of the thermoelectric cooling system.

Insulation is another important factor in the efficiency of a thermoelectric refrigerator. Using materials with good insulating properties, such as Styrofoam or fiberglass, can help to retain the cold temperature inside the refrigerator. It is also recommended to use composite aluminum for the inner and outer walls of the refrigerator, as it can increase the efficiency of the cooling system.

The design and construction of a thermoelectric refrigerator presents an affordable and easy-to-use alternative to conventional refrigeration systems. By considering factors such as the number of Peltier modules used and the quality of insulation materials, it is possible to optimize the performance of the refrigerator and achieve efficient and effective cooling.

6. RECOMMENDATION

One important consideration in the design of a thermoelectric refrigerator is the number of Peltier modules used. Using a larger number of Peltier modules can increase the cooling power of the refrigerator, but it will also increase the electricity consumption. To reduce electricity usage, it is recommended to use Peltier modules with low voltage consumption, such as 3-amp modules.

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