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Solar Energy based Refrigeration System using Peltier Device

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ABSTRACT: In the recent years, we have many problem such as energy crises and environment degradation due to the increasing CO_2 emission and ozone layer depletion has become the primarily concern to both developed and developing countries. Our paper utilizes the solar energy for its operation. Solar refrigeration using thermoelectric module is going to be one of the most cost effective, clean and environment friendly system. This paper does not need any kind of refrigerant and mechanical device like compressor, prime mover, etc for its operation. The main purpose of this project is to provide refrigeration to the remote areas where power supply is not possible.

Keywords: Carbon dioxide, Thermoelectric, Refrigeration, Peltier

I. INTRODUCTION

Renewable & alternative non-conventional green energy technologies used for heat-pumping applications have shown real merits and received renewed interest in recent years especially in small-scale portable heating applications. Solar-driven thermoelectric heat pumping is one of these innovative technologies [1]. Solar energy is the most low cost, competition free, universal source of energy as sunshine's throughout. This energy can be converted into useful electrical energy using photovoltaic technology. Thermoelectric heating (or cooling) technology has received renewed interest recently due to its distinct features compared to conventional technologies, such as vapour-compression and electric heating (or cooling) systems. Thermoelectric (TE) modules are solid-state heat pumps (or refrigerators in case of cooling) that utilize the Peltier effect between the junctions of two semiconductors. The TE modules require a DC power supply so that the current flows through the TE module in order to cause heat to be transferred from one side of the TE module to other, thus creating a hot and cold side [2, 3].The main objective of the heating & cooling system service is to be suitable for use by the people who live in the remote areas of country where load-shading is a major problem. The system can also be used for remote parts of the world or outer conditions where electric power supply From last century till now refrigeration has been one of the most important factors of our daily life. The current tendency of the world is to look at renewable energy resources as a source of energy. This is done for the following two reasons; firstly, the lower quality of life due to air pollution; and, secondly, due to the pressure of the ever increasing world population puts on our natural energy resources. From these two facts comes the realization that the natural energy resources available will not last indefinitely. The basic idea is implementation of photovoltaic driven refrigerating system powered from direct current source or solar panel (when needed) with a battery bank. In 1821, the first important discovery relating to thermoelectricity occurred by German scientist Thomas Seebeck who found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals, provided that the junctions of the metals were maintained at two different temperatures. Without actually comprehending the scientific basis for the discovery, See beck, falsely assumed that flowing heat produced the same effect as flowing electric current. Later, in 1834, while investigating the See beck Effect, a French watchmaker and part-time physicist, Jean Peltier found that there was an opposite phenomenon where by thermal energy could be absorbed at one dissimilar metal junction and discharged at the other junction when an electric current flows within the closed circuit. Afterwards, William Thomson described a relationship between See beck and Peltier Effect without any practical application. After studying some of the earlier thermoelectric work, Russian scientists in 1930s, inspired the development of practical thermoelectric modules based on modern semiconductor technology by replacing dissimilar metals with doped semiconductor material used in early experiments. The Seebeck, Peltier and Thomson effects, together with several other phenomena, form the basis of functional thermoelectric modules. Thermoelectric Refrigeration aims at providing cooling effect by using thermoelectric effects rather than the more prevalent conventional methods like those using the 'vapour compression cycle' or the 'gas compression cycle'.

Definition. The Seebeck coefficient is the ratio between the electric field and the temperature gradient. The See beck coefficient can be thought of as a measure of the coupling between the thermal and electrical currents in a material.

The Peltier coefficient of the junction is a property depending on both materials and is the ratio of the power evolved at the junction to the current flowing through it. The Thomson coefficient is the ratio of the Power evolved per unit volume in the sample to the applied current and temperature gradient.

II. CONSTRUCTION OF REFRIGERATION SYSTEM

The construction setup of the refrigerator is as follows: [2]

- Thermo-electric module
- Refrigeration chamber
- Battery
- Solar cell
- Frame

A. Thermo-electric module

A thermo-electric module (TEM) is a solid state current device, which, if power is applied, move heat from the cold side to the hot side, acting as a heat exchanger. This direction of heat travel will be reversed if the current is reversed. It is a phenomenon that is opposite to the See beck effect. Combination of many pairs of p- and n-semiconductors allows creating cooling units - Peltier modules of relatively high power. A Peltier module consists of semiconductors mounted successively, which form p-n- and n-p-junctions. Each junction has a thermal contact with radiators. When switching on the current of the definite polarity, there forms a temperature difference between the radiators one of them warms up and works as a heat sink, and the other work as a refrigerator. A TE module is composed of two ceramic substrates that give foundation and also electrical insulation to p-type and n-type semiconductors. The TE module is composed of silicon bismuth semiconductor because this pair gives the highest COP. Specification,

1. Material used- Silicon - Bismuth
2. A = 0.04 x 0.04 = 0.0016 m2
3. Q max =33.3 watt
4. V max = 14.8 v dc
5. I max =6 amp

B. Refrigeration chamber

The chamber used is same as that of the chambers used in conventional refrigeration. The chamber can be of any volume, shape and size. For experimentation purposes the volume of the chambers is kept low. Insulation provided to the chamber is done by polystyrene and aluminum casing is done in the inner side of insulation to provide better cooling. We have used specific chamber and is as follows,

1. The size of the box is,
   - Width - 28.7 cm,
   - Length - 31.8 cm,
   - Height - 33.7 cm.
2. The power capacity is 60 W
3. The capacity of cooling chamber is 7.8 L
4. The voltage is 240 V to 220 V AC and 12 V DC.

C. Battery

The battery is an electrochemical converting chemical energy into electrical energy. The main purpose of the battery is to provide a supply of current for operating the cranking motor and other electrical units.
Specification,
1. Voltage 12v
2. Current 7.2Ah

D. Solar cell

The direct conversion of solar energy is carried out into electrical energy by conversion of light or other electromagnetic radiation into electricity.

1. The dimensions of the panel are-
   - Length – 48.5 cm,
   - Width – 35 cm.
2. Number of sub-cells used is 72
3. Dimension of the sub-cells is,
   - Length – 4.8 cm
   - Width – 4 cm.
4. Maximum power is 20 W
5. Voltage is 17 V
6. Current is 1.16 A

E. Frame

Fig. 1. Refrigeration frame.

III. THERMOELECTRIC DEVICES

A Peltier element is a thermoelectric cooler, or TEC, which is simply a small heat pump. In 1821 J.T Seebeck discovered that two dissimilar metals connected at two different junctions create a micro voltage between them if held at two different temperatures [3]. If two wires are connected, for example iron and copper, and the other ends applied to the terminals of a galvanometer a voltage can be recorded if the junction between the wires is heated. The wires are called a thermocouple [4] J. Peltier realised, in 1834, that the inverse effect is possible as well. If a voltage is applied to a thermocouple a temperature difference will be initiated between the junctions. This is known as the Peltier effect [3]. A heating or cooling effect of the junction is created depending on the direction of the current.

In 1855 the dependency between the temperature change and the current application was proven by W. Thomson (or Lord Kelvin) who, by applying thermodynamics, established the relationship between the coefficients that described the Peltier and Seebeck effects, which is now known as the Thomson effect [4]. This effect described reversible heating or cooling when there is a temperature gradient along with an electric current. What happens is the electrons carrying out the current possess different energy depending on the material. When the current reaches the junction it is transferred from one material to another and the energy is altered, causing the junction to heat up or cool down. Likewise, if the junction is heated the electrons can pass from the material with lower energy to that with higher, giving rise to an electromagnetic force.

A. Peltier Effect

If direct current is passed through two dissimilar metals then a potential difference will be developed across the two dissimilar metals. There will be cooling at one junction and heating at another junction. Peltier says that charge is directly proportional to current which means when voltage is applied to the Peltier device then current will be developed and due to the current, charge will be generated and due to charge a potential difference will be developed between two dissimilar metal [5].

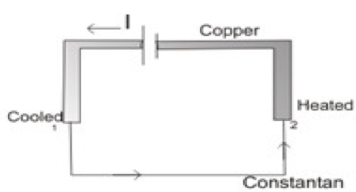

Fig. 2. Peltier Effect.

$$q \; \alpha \; I \qquad \ldots(1)$$
$$q = \pi ab \; I \qquad \ldots(2)$$

Where

q= Peltier heating and cooling rate.

πab= Peltier coefficient.

B. Thomson Effect

In different materials, the Seebeck coefficient is not constant in temperature, and so a spatial gradient in temperature can result in a gradient in the Seebeck coefficient. If a current is driven through this gradient then a continuous version of the Peltier effect will occur. This Thomson effect was predicted and subsequently observed by Lord Kelvin in 1851. It describes the heating or cooling of a current-carrying conductor with a temperature gradient [5].

If a current density J is passed through a homogeneous conductor, the Thomson effect predicts a heat production rate q per unit volume of:

$$\dot{q} = kJ.\nabla T \qquad \ldots(3)$$

C. Seebeck Effect

The Seebeck effect is the conversion of heat directly into electricity at the junction of different types of wire. It is named for the Baltic German physicist Thomas Johann Seebeck, who in 1821 discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the joints. This was because the electron energy levels in each metal shifted differently and a voltage difference between the junctions created an electrical current and therefore a magnetic field around the wires. Seebeck did not recognize there was an electric current involved, so he called the phenomenon "thermomagnetic effect" [5]. Danish physicist Hans Christian Ørsted rectified the oversight and coined the term "thermoelectricity". The Seebeck effect is a classic example of an electromotive force (emf) and leads to measurable currents or voltages in the same way as any other emf. Electromotive forces modify Ohm's law by generating currents even in the absence of voltage differences (or vice versa); the local current density is given by

$$J = \sigma(-\nabla V + \text{Eemf}) \qquad \ldots(4)$$

where V is the local voltage and σ is the local conductivity. In general, the Seebeck effect is described locally by the creation of an electromotive field:

E=

$$E = -S\nabla\text{T} \qquad \ldots(5)$$

Where S is the Seebeck coefficient (also known as thermopower), a property of the local material, and ∇T is the gradient in temperature T.

D. Seebeck Cofficient

The Seebeck coefficient (also known as thermopower, thermoelectric power, and thermoelectric sensitivity) of a material is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material, as induced by the Seebeck effect. The SI unit of the Seebeck coefficient is volts per kelvin (V/K), although it is more often given in microvolts per kelvin (μV/K). The use of materials with a high Seebeck coefficient is one of many important factors for the efficient behaviour of thermoelectric generators and thermoelectric coolers. More information about high-performance thermoelectric materials can be found in the Thermoelectric materials article. In thermocouples the Seebeck effect is used to measure temperatures, and for accuracy it is desirable to use materials with a Seebeck coefficient that is stable over time [6].

$$S = -\frac{\Delta \text{V}}{\Delta \text{T}} \qquad \ldots(6)$$

Where ΔV is the thermoelectric voltage seen at the terminals.

The Seebeck coefficient is defined in terms of the portion of electric current driven by temperature gradients, as in the vector differential equation:

$$J = -\sigma \nabla V - \sigma S \nabla T \quad \ldots(7)$$

IV. PELTIER MODEL

A thermoelectric (TE) cooler, sometimes called a thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump [1]. By applying a low voltage DC power source to a TE module; heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity (plus and minus) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications.

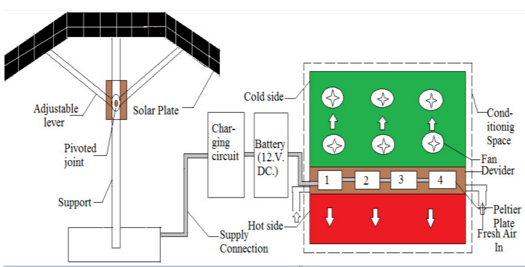

Fig. 3. Experimental working model.

The TEM operating principle is based on the Peltier effect. The Peltier effect is a temperature difference created by applying a voltage between two electrodes connected to a sample of semiconductor material to create a hot side and a cold side. The cold side of the thermoelectric module is utilized for air conditioning purposes; provide cooling to the cold space. On the other hand, the heat from the hot side is utilized for heating purpose.

A. Features of Peltier Module

1. Peltier module can convert thermal energy into electricity, or when electricity is provided to the peltier module then absorption of heat(cool side) on one side and rejection of heat(hot side) on other side.
2. Conventional systems can use or generate harmful gasses like Chloro Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs). The peltier module can't use or generate these harmful gasses.
3. The conventional refrigeration system can generate some noise during operation. The peltier module can't generate any noise during operation. It is quite in operation.
4. Peltier module can operate on DC power source.
5. By using proper closed loop circuit, the peltier module can control precise temperature.
6. Long life, with mean time between failures (MTBF) exceeding 100,000 hours.
7. Controllable via changing the input voltage/current.

B. General Mechanical Properties of Thermoelectric Material

Thermoelectric material has following mechanical properties.

Table 1: Mechanical properties of thermoelectric material.

Material	Young's modulus	Fracture strength	Hardness	Fracture toughness
Skutterudite	133-140	35- 85	-	1.1-1.8
Oxides	85-210	-	2.5- 11.75	2.69-4.78
Antimonide	74	65	1.56	0.69
PbTe Based	54-55	28	0.98- 1.27	-

There are different thermoelectric material are used like skutterudite, oxides, antimonide, PbTe based etc. Each material has different mechanical properties. In above table mention the values of mechanical properties of each material, which is helpful during the selection of thermoelectric module.

C. Application Thermoelectric

Following are the application where peltier module has been used

A. Thermoelectric generator
B. Thermoelectric cooler
C. Water condensation using thermoelectric cooler
D. Medical Freezer

D. Types of Peltier Element

The Zt value is calculated using the formula:
Z = S2 Σ x T/K
Where:
T = absolute temperature
S = Seebeck coefficient
Σ = electrical conductivity
K = thermal conductivity

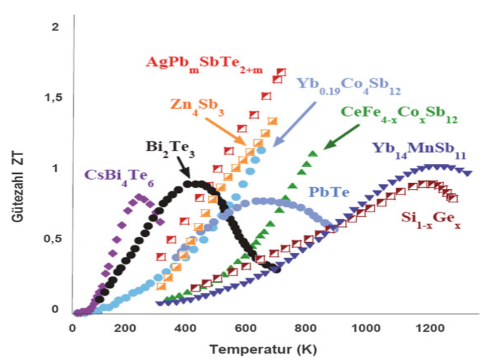

Fig. 4. Chart for diversity of Peltier element material.

Design of Peltier element

- High mechanical strength
- Low shear stress

- All interfaces between components must be flat, parallel, and clean

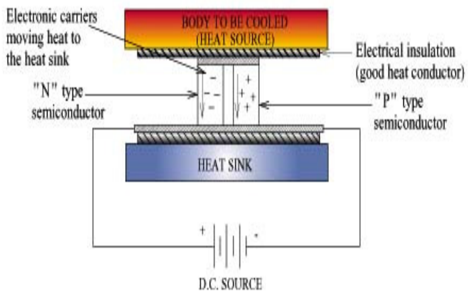

Fig. 5. Cross section of peltier element view.

A choice of different Peltier elements in different categories is High Performance, High Temperature, Micro, Multi-Stage, Special Shapes, series-parallel connection and Standard. From these it is possible to immediately eliminate High Temperature, Multi-Stage, Micro, Series-Parallel connection and Special Shapes, due to over design to the requirements and costs. Therefore, selection is made between High Performance and Standard.

V. RENEWABLE RESOURCES

Renewable energy sources also called non-conventional energy are sources that are continuously replenished by natural processes. For example, solar energy, wind energy, bio-energy - bio-fuels grown sustain ably), hydropower etc., are some of the examples of renewable energy sources.

A renewable energy system converts the energy found in sunlight, wind, falling-water, sea-waves, geothermal heat, or biomass into a form, we can use such as heat or electricity. Most of the renewable energy comes either directly or indirectly from sun and wind and can never be exhausted, and therefore they are called renewable.

However, most of the world's energy sources are derived from conventional sources-fossil fuels such as coal, oil, and natural gases. These fuels are often termed non-renewable energy sources. Although, the available quantity of these fuels are extremely large, they are nevertheless finite and so will in principle ‘run out’ at some time in the future .

Renewable energy sources are essentially flows of energy, whereas the fossil and nuclear fuels are, in essence, stocks of energy

Various forms of renewable energy [7-8]:

- Solar energy
- Wind energy
- Bio energy
- Hydro energy
- Geothermal energy
- Wave and tidal energy

This section focuses on application potential of commercially viable renewable energy sources solar energy.

A. Solar Energy

Solar energy is the most readily available and free source of energy since prehistoric times. It is estimated that solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year. India receives solar energy in the region of 5 to 7 kWh/m^2 for 300 to 330 days in a year. This energy is sufficient to set up 20 MW solar power plants per square kilometre land area. Solar energy can be utilized through two different routes, as solar thermal route and solar electric (solar photovoltaic) routes. Solar thermal route uses the sun's heat to produce hot water or air, cook food, drying materials etc. Solar photovoltaic uses sun’s heat to produce electricity for lighting home and building, running motors, pumps, electric appliances, and lighting.

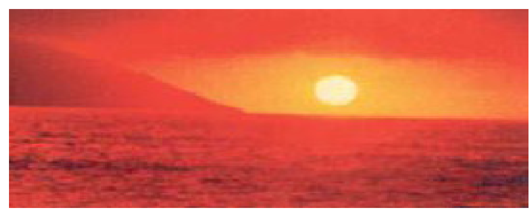

Fig. 6. Solar Energy.

B. Solar Thermal Energy Application

In solar thermal route, solar energy can be converted into thermal energy with the help of solar collectors and receivers known as solar thermal devices. The Solar-Thermal devices can be classified into three categories:

➢ Low-Grade Heating Devices - up to the temperature of 100°C.

➢ Medium-Grade Heating Devices -up to the temperature of 100°-300°C

➢ High-Grade Heating Devices -above temperature of 300°C

Low-grade solar thermal devices are used in solar water heaters, air-heaters, solar cookers and solar dryers for domestic and industrial applications.

Solar water heaters. Most solar water heating systems have two main parts: a solar collector and a storage tank. The most common collector is called a *flat-plate collector* (Fig. 7). It consists of a thin, flat, rectangular box with a transparent cover that faces the sun, mounted on the roof of building or home. Small tubes run through the box and carry the fluid – either water or other fluid, such as an antifreeze solution – to be heated. The tubes are attached to an absorber plate, which is painted with special coatings to absorb the heat. The heat builds up in the collector, which is passed to the fluid passing through the tubes.

Fig. 7. Solar Flat plate collector.

An insulated storage tank holds the hot water. It is similar to water heater, but larger is size. In case of systems that use fluids, heat is passed from hot fluid to the water stored in the tank through a coil of tubes.
Solar water heating systems can be either active or passive systems. The active systems, which are most common, rely on pumps to move the liquid between the collector and the storage tank. The passive systems rely on gravity and the tendency for water to naturally circulate as it is heated. A few industrial application of solar water heaters are listed below:

- Hotels: Bathing, kitchen, washing, laundry applications
- Dairies: Ghee (clarified butter) production, cleaning and sterilizing, pasteurization
- Textiles: Bleaching, boiling, printing, dyeing, curing, ageing and finishing
- Breweries & Distilleries: Bottle washing, wort preparation, boiler feed heating
- Chemical /Bulk drugs units: Fermentation of mixes, boiler feed applications
- Electroplating/galvanizing units: Heating of plating baths, cleaning, degreasing applications
- Pulp and paper industries: Boiler feed applications, soaking of pulp.

C. Solar Electricity Generation

Solar Photovoltaic (PV). Photovoltaic is the technical term for *solar electric*. Photo means "light" and voltaic means "electric". PV cells are usually made of silicon, an element that naturally releases electrons when exposed to light. Amount of electrons released from silicon cells depend upon intensity of light incident on it. The silicon cell is covered with a grid of metal that directs the electrons to flow in a path to create an electric current.
This current is guided into a wire that is connected to a battery or DC appliance. Typically, one cell produces about 1.5 watts of power. Individual cells are connected together to form a solar *panel* or *module*, capable of producing 3 to 110 Watts power. Panels can be connected together in series and parallel to make a solar *array* (Fig. 6), which can produce any amount of Wattage as space will allow. Modules are usually designed to supply electricity at 12 Volts. PV modules are rated by their peak Watt output at solar noon on a clear day. Some applications for PV systems are lighting for commercial buildings, outdoor (street) lighting, rural and village lighting etc. Solar electric power systems can offer independence from the utility grid and offer protection during extended power failures. Solar PV systems are found to be economical especially in the hilly and far flung areas where conventional grid power supply will be expensive to reach.

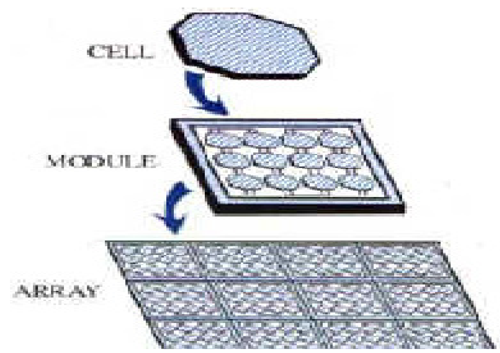

Fig. 8. Solar Photovoltaic Array.

PV tracking systems is an alternative to the fixed, stationary PV panels. PV tracking systems are mounted and provided with tracking mechanisms to follow the sun as it moves through the sky. These tracking systems run entirely on their own power and can increase output by 40%.
Back-up systems are necessary since PV systems only generate electricity when the sun is shining. The two most common methods of backing up solar electric systems are connecting the system to the utility grid or storing excess electricity in batteries for use at night or on cloudy days.

Performance. The performance of a solar cell is measured in terms of its efficiency at converting sunlight into electricity. Only sunlight of certain energy will work efficiently to create electricity, and much of it is reflected or absorbed by the materials that make up the cell. Because of this, a typical commercial solar cell has an efficiency of 15%—only about one-sixth of the sunlight striking the cell generates electricity. Low efficiencies mean that larger arrays are needed, and higher investment costs. It should be noted that the first solar cells, built in the 1950s, had efficiencies of less than 4%.

Solar Water Pumps. In solar water pumping system, the pump is driven by motor run by solar electricity instead of conventional electricity drawn from utility grid. A SPV water pumping system consists of a photovoltaic array mounted on a stand and a motor-pump set compatible with the photovoltaic array. It converts the solar energy into electricity, which is used for running the motor pump set. The pumping system draws water from the open well, bore well, stream, pond, canal etc.

VI. ADVANTAGES

We believe that thermoelectric cooling offers a number of advantages over traditional refrigeration methods, as:
1. System have no moving parts,
2. No Freon's or other liquid or gaseous refrigerants required,
3. Precise temperature control,
4. High reliability & durability - We guarantee 5 years hours of no failures,
5. Compact size and light weighted,
6. Noiseless operation,
7. Relatively low cost and high effectiveness,
8. Easy for maintenance,
9. Eco-friendly C-pentane, CFC free insulation.

VII. FUTURE SCOPE

To build a real time model replacing both air conditioner & room heater in one system i.e. thermoelectric hot & cold room conditioner.

VIII. APPLICATIONS OF SYSTEMS

1. Can be uses for remote place where electric supply is not available,
2. Medical and pharmaceutical equipment,
3. Military applications,
4. Laboratory, scientific instruments, computers and video cameras.
5. In restaurants /hotels

IX. CONCLUSION

In current, the refrigeration system is extensively used as a cooling agent but it consumes lots of electricity and releases various types of gases like CO_2, CO which is harmful for the atmosphere and produce global warming and climate change. This paper covers all the relevant concerns for the design of refrigeration system using peltier device based on solar energy. The solar energy is renewable energy source which will never be end. The existing system was designed using non-renewable sources and its produces excessive amount of harmful gases which create energy crisis and depletion the ozone layer also. So in future work, need to design the refrigeration system based on renewable energy resource like solar energy using the peltier effect. A portable Heating & Cooling system was fabricated using thermoelectric module & electric control unit & tested for the cooling and heating purpose.

The system is self powers & can be used in isolated & a remote part of the country where load-shading is a major problem. The important aspect to be noted is that it is a onetime investment & is free from maintenance. Further improvement in the efficiency of the system may be possible through improving module contact-resistance & thermal interfaces. This could be achieved by installing more modules in order to cover a greater surface area of the system.

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