CHAPTER ONE
INTRODUCTION

1.1 Background Of Study

Each year, more than 1.5 million people die from a disease that could have been prevented with vaccination. In order to maintain their full potency, vaccines need to be stored between 2°C and 8°C and this requirement applies to the whole supply chain, or cold chain from manufacturing to administration to beneficiaries Every year, more than 25% of vaccines are wasted. One of the main reasons for this wastage is the lack of cold chain continuity in low-income settings, where electricity is scarce (WHO, 2019).

Recently, several advances have been made in cooling technologies to store and transport vaccines. The current paper presents a review of refrigeration technologies based on scientific publications, industry white papers and other grey literature. For each refrigeration method, we describe its working principle, the best performing devices available as well as the remaining research challenges in order to obtain a very high degree of performance enhancement. Finally, we comment on their applicability for vaccine transport and storage (Ellab, 2021).

Vaccines are very crucial for treating preventable diseases, but it needs a constant environment by maintaining a certain steady temperature. Currently it is a barrier in healthcare sector. More than 25% of vaccines are annually wasted, primarily due to the inability to maintain the optimal temperature range along the cold chain. This cold chain involves logistical challenges, particularly in low-income settings where equipment might be defective, electricity supply unreliable, roads impassable and health workers not adequately trained. Depending on the number of vaccines to be carried, each stage of the cold chain (national, regional, villages) requires specific transport and storage equipment. While the choice of transport is mainly influenced by road conditions, the choice of storage equipment depends on the availability of energy resources (mainly electricity), the duration of transportation or storage as well as the volume of vaccines.

To ensure a safe and effective delivery of immunization, the World Health Organization (WHO) has developed the Performance, Quality and Safety (PQS) system. The status of refrigeration techniques for vaccine storage and transportation in low-income settings consists of a list of performance specifications and test procedures to prequalify cold chain equipment. To help procurement agencies make decisions, the PQS catalogue lists prequalified cold chain equipment. The refrigeration equipment falls into two main categories: passive and active.

Passive refrigeration devices do not require any external source of energy during use. Such equipment consists of (i) long-term passive containers, which are used to store vaccines at health facilities where electricity is unreliable, (ii) vaccine carriers and (iii) cold boxes, the latter two being used rather to transport vaccines from the facility to the beneficiaries. The performance of passive refrigeration equipment is mostly assessed by its cold life, i.e., the duration it is able to maintain an inner temperature range of 2-8°C.

Active refrigeration equipment requires access to energy in the form of heat or electricity during use. This approach is more appropriate for storage in health facilities than for transportation. When electricity is available for 8 hours or more per day and power outages are shorter than 48 hours, on-grid equipment is recommended by the WHO. On the contrary, when electricity is available less than 8 hours per day with recurrent power outages longer than 48 hours, devices able to generate their own power such as heat-driven or solar refrigerators are preferred. The performance of an active refrigeration system is represented by its efficiency to convert input energy such as electricity or heat to cooling capacity (i.e., capacity to remove heat from a cold source). This measure is called the coefficient of performance (COP) and is computed as the ratio between cooling capacity (output) and supplied energy (input). The current review compares the main refrigeration methods, passive and active, for vaccine storage or transportation, their respective performance and technologies being currently developed or already available on the market. The research challenges to improve the performance (efficiency and/or cold life) of these refrigeration methods are also identified (Elsevier B.V, 2020).

1.1.1 Solar Power Generation

The science of generating electricity with solar panels all comes down to the photovoltaic effect. First discovered in 1839 by Edmond Becquerel, the photovoltaic effect can be generally thought of as a characteristic of certain materials (known as semiconductors) that allows them to generate an electric current when exposed to sunlight.

The process of generating solar electricity starts with solar cells, the individual pieces that make a larger solar panel. Solar cells are usually made from the element silicon (atomic #14 on the periodic table). Silicon is a nonmetal semiconductor that can absorb and convert sunlight into electricity – we also use silicon in almost every computer on the planet. There are a few different types of semiconductors typically used in solar cells, and silicon is by far the most common, used in 95% of solar cells manufactured today. Cadmium-telluride and copper indium gallium Di selenide are the two main semiconductor materials used in thin-film solar panel production.

There are two layers of silicon used in photovoltaic cells, and each one is specially treated, or "doped", to create an electric field at the junction between the layers. This electric field forces loose electrons to flow through the solar cell and out of the silicon junction, generating an electrical current. Phosphorus and boron are commonly used as positive and negative doping agents, respectively, to create the positive and negative sides to a photovoltaic cell. Metal plates on the sides of each solar cell collect the electrons pushed out by the electric field, and transfer them to connecting wires. At this point, electrons flow as electricity through the wiring to a solar inverter and then throughout your thermoelectric device.

1.1.2 Benefits Of Solar Refrigeration

Solar powered refrigeration has demonstrated four main benefits for the vaccine cold chain relative to absorption refrigeration fueled by kerosene and gas. First, laboratory testing has confirmed higher performance on several critical parameters, most importantly temperature control. Second, system reliability has been adequate where WHO PQS recommendations have been respected and regular maintenance and repair service have been sustained. Third, the lifetime cost of direct-drive solar remains lower than absorption refrigeration and is increasingly competitive with grid-powered systems. Finally, solar systems may be an environmental improvement over absorption refrigerators, eliminating the need to burn fossil fuels. In fact, absorption-cycle refrigeration is fundamentally less efficient than solar or grid-electric compression refrigeration, consuming more energy to provide the same cooling.

Comparative annualized costs of different WHO PQS approved vaccine refrigerators for use in areas with unreliable electricity. Solar refrigerator temperature performance is superior laboratory testing has shown that the standard of temperature control in solar compression refrigeration is higher than kerosene or gas absorption refrigeration (WHO unpublished confidential data). Control remains within a narrower temperature range and with fewer excursions outside the recommended range. With current PQS-qualified direct-drive solar refrigerators, during periods of low sun, the autonomy of the systems (the time that the refrigerator can continue to cool the vaccine compartment under poor solar conditions such as heavy cloud and rain) is at least three days and as long as ten days in some models considerably better than the 5 hours of cold life achieved by absorption systems when fuel is not available. Among refrigerators that have been prequalified by WHO, solar models with ice-freezing capability produce more ice per 24 hours than absorption models. Finally, and most important, all current PQS prequalified solar refrigerators are designed to avoid accidental freezing of vaccines, a frequent problem for most absorption systems. Today, the direct-drive system is the option of choice, but there are currently two conditions where battery systems may be a better choice. First, in areas where longer autonomy is required than a solar direct-drive refrigerator can provide, such as locations where there are several consecutive weeks of heavy cloud cover expected every year. Second, if ice packs must be prepared on site, currently only a limited selection of PQS-prequalified direct-drive solar devices have combined refrigerator and freezer capability. However, this number is likely to increase as manufacturers are responding to the need to make ice in the field.

1.1.3 Principle Of Thermoelectric Device

The structure of thermoelectric modules is generally described as elements of n and p type thermoelectric material sandwiched between two ceramic plates and connected in series. The elements are solid-state, vibration-free, noise-free heat pumps, which move heat from one surface to another when direct current electricity is applied to it. If the heat at the hot side is dissipated to the ambient environment by a heat sink, this assembly becomes a cooling unit. Not only used for heat transfer, thermoelectric modules are widely used to generate electrical power by converting heat energy to electrical current which allows for waste heat recovery. Many new, promising thermoelectric generating materials have been developed in recent years, contributing significantly in increasing power generation efficiency.

1.2 Statement Of Problem

The vaccine is the major economic cost and component of the worldwide battle against infectious and transmitted diseases. WHO ISCL states that about 2.8 million vaccine doses were lost in east Africa includes Nigeria. This lack of solar powered cold storage in the vaccine supply chain has not only led to the shortage in vaccination coverage but has also led to mortality and morbidity of human life.

Since 2005, UNICEF has supplied more than 6500 solar-powered vaccine refrigerators (6048 were battery based and 497 were direct drive), with the greatest number supplied to Africa.
There has been a number of challenges constraining the performance and reliability of solar vaccine refrigerators. Four challenges listed below are drawn from a review of in-country experience and are each discussed in the following sections:

- Inadequate system design and installation quality.
- Maintenance and spare parts supply not addressed.
- Inappropriate use.
- Lack of feedback on field performance.

Consequent to the aforementioned problems, Peltier mini refrigeration was equally introduced in different countries to overcome the wastage of vaccines. However, this mini refrigeration system has issues of efficiency and cooling time (taking too much cooling time to come to the vaccine temperature requirement).

The efficiency and cooling time of TEC is depending on COP; one way of addressing the better efficiency is improving COP. COP depends on the current supply of the Peltier module and the temperature difference between the two sides of TEM.

1.3 Aim and Objectives of The Study

This project work titled "Intelligent Solar Powered Immunization Vaccine Storage System" is aimed to design and implement a solar photovoltaic power supply based portable mini-refrigeration system utilizing the Peltier effect. To achieve this goal, the study has the following specific objectives:

- To develop a solar panel that will generate electricity from sunlight.
- To determine the rating of the charge controller and capacity of the battery.
- To develop a cooling holder that will isolate the vaccine and have a control system ensures that the required temperature is maintained
- To develop the User and Operator Interface that will display the temperature of the vaccines.
- Finally, to develop a computerized system that can monitor the potency of the vaccine and warns when the cold chain temperature drops.

1.4 Significance Of the Study

The shortage of energy sources and air pollution are the major issues within the world as well as in our nation. So, the world is moving the energy source utilization from non-renewable sources to the renewable energy source. Renewable energy sources are eco-friendly with the environment.

Currently, this renewable energy source is accepted in many countries including Nigeria. Due to this reason, this research work will help the country in the development of eco-friendly products. This research work will equally be adding value to the Health Center in the cases of emergency first aid service, to university workers and the student. It can also provide major help for the ongoing coronavirus (COVID-19) vaccine transport through the regional public health institution for immunization purpose.

Finally, the Peltier mini refrigeration system has enormous use in the field of medical applications, it has too many advantages over the conventional fridge for small-scale applications in terms of easy manufacturing, eco-friendly, and small initial capital. This research work will turn to an entrepreneurship business idea for the Nigerian market.

1.5 Scope Of the Study

This study only covers the use of solar powered system that will give and maintain the temperature coverage between 2℃ and 8℃, using thermoelectric device. It also covers the mathematical modeling of solar panel, Peltier module, and cooling load of the selected area.

1.6 Limitations Of the Study

This study did not consider the use of grid electricity and compressor cooling effect. Also, the purchased electronic items are not industrial grade because of the difficulty in procurement of these items during the COVID-19 pandemic. Consequently, the items acquired had a different characteristic than initially anticipated for the prototype.

1.7 Definition of Terms

These are terms that are used often throughout this report.

Vaccine: It is any substance used to stimulate the production of antibodies and provide immunity against one or several vaccine preventable diseases.

Cold Chain System: This is a set of rules and procedures that ensure the proper storage and distribution of vaccines to health services from the national to the local level.

Immunization: This is the process by which an immune system is been fortified against infectious diseases.

Coefficient of Performance: This is defined as the heat removed from the cold reservoir $\mathbf{Q_{cold}}$, (i.e., inside a refrigerator) divided by the work **W** done to remove the heat (i.e. the work done by the compressor).

PQS: This is a standard or set of rules set by WHO for all manufacturers of vaccine storage systems.

Grid: Grid electricity is an electricity that is gotten from the transformer. This type of electricity is not usually constant in Nigeria but its worse for people in the rural areas.

1.8 Organization of the Report

This thesis is organized into five chapters:

Chapter 1: Discuses introduction of the research work, statement of the problems, objectives, Research questions, significance, scope, and limitation of the research.

Chapter 2: Includes a literature review of the previous work and theoretical background of the Thermoelectric refrigeration system and different types of the thermoelectric effect, The working principle of Peltier cooling, and an overview of the solar panel Technology.

Chapter 3: Discussed material and Methods. The analysis of data, cooling load calculation, Peltier module modeling, solar Module modeling and the proposed system implementation are covered.

Chapter 4: Discussed implementation, result and discussion, while

Chapter 5: Discussed Conclusion and recommendation.

CHAPTER TWO
LITERATURE REVIEW

2.1 Review on past works

In this chapter, we are going to review the previous works and the methods they used to preserve vaccines within the last 10 years, since vaccines are a major economic cost and component of the worldwide battle against infectious disease. In 2011, UNICEF bought 2.5 billion doses of vaccines, and spent more than one billion dollars on vaccines (UNICEF, 2011). Within the category of development assistance for maternal and child health, donors spent $3.2 billion on child vaccines in 2014 (Dieleman, Murray, & Haakenstad, 2015). Still, for children in developing countries, health care inequities are prominent, and access to preventative therapies and drugs is limited (Gates, 2012). One reason these countries lack enough vaccination coverage is due to insufficient cold storage (without freezing) in the vaccine supply chain (Humphreys, 2011). Breakdown of the vaccine cold chain is believed to be a major contributor to late 20th-century polio outbreaks in southern Africa (Schoub, & Cameron, 1996). Many vaccines must be maintained in a temperature range of 2-8°C to remain potent. Indeed, previous studies have shown that cold chain wastage (due to the failure to maintain vaccines in a safe temperature range, the need to discard unused portions of opened vaccine vials, and improper handling and expiration) can be as high as 60-70% (Wallace, Willis, Nwaze, & Dieng, 2017; Zaffran et al., 2013).

2.2 Existing technologies

Even though vaccine carriers and cold boxes are already widespread on the market, their cold life could still be improved and the coolant packs-related constraints could be minimized. The three devices presented below were developed with the support and/or collaboration of the Bill & Melinda Gates Foundation. The Indigo Cooler showed promising results. It consists of a vacuum flask vaccine carrier with a 2 L inner storage capacity that can be worn like a backpack. Based on evaporative refrigeration, it does not require any electricity, ice or battery during use.

The pressure inside the device is initially lowered so that water evaporates at 5°C. When exposed to a heat source, the water inside the walls of the device evaporates, keeping the vaccine compartment cool. Once all the water has evaporated and moved to another compartment, it needs to be pressurized again at a charging station so that the cycle can restart. This process allows the storage temperature range to be maintained for 5 days when the ambient Capacity Short range Long range Vaccine carrier 0.5-5 L > 15 h > 30 h Long-term cold box 5 L - > 35 d Conventional cold box 5-25 L > 48 h > 96 h Large storage capacity cold box > 100 L > 24 h > 48 h temperature is 43°C. No evidence was found of the Indigo Cooler being available on the market or whether it has been PQS-prequalified by the WHO, despite field tests conducted at multiple locations. As for long-term cold boxes, only one device has been prequalified by the WHO PQS programme, namely the Arktek Passive Vaccine Storage Device (PSD). The device is designed for stationary use, with a 5.4 L vaccine storage capacity. It relies on the principle of a vacuum flask with multilayer insulating materials (i.e. cryogenic dewar) and is not powered by electricity but requires ice packs to be renewed monthly. When the ambient temperature goes up to 43°C, the device ensures a temperature in the range of 0-10°C for at least 35 days. The Arktek PSD is currently sold to leading healthcare stakeholders (WHO, MédecinsSansFrontières, UNICEF, etc.) and its indicated price in the UNICEF Supply Catalogue is US$ 2,393.

The Sure Chill company also developed a long-term cold box but based on Vacuum Insulated Panels and providing freeze protection. The device with a vaccine storage capacity of 7.8 L was field tested and able to maintain an internal temperature below 10°C for 33- 42 days. It is currently undergoing a second phase of field pilot studies and is in the process of being scaled up. However, no evidence was found of WHO prequalification status.

2.2.1 Review on cooling systems

Air conditioning, or cooling, is more complicated than heating. Instead of using energy to create heat, air conditioners use energy to take heat away. The most common air conditioning system uses a compressor cycle (similar to the one used by your refrigerator) to transfer heat from your house to the outdoors.

Picture your house as a refrigerator. There is a compressor on the outside filled with a special fluid called a refrigerant. This fluid can change back and forth between liquid and gas. As it changes, it absorbs or releases heat, so it is used to “carry” heat from one place to another, such as from the inside of the refrigerator to the outside. Simple, right?

Well, no. And the process gets quite a bit more complicated with all the controls and valves involved. But its effect is remarkable. An air conditioner takes heat from a cooler place and dumps it in a warmer place, seemingly working against the laws of physics. What drives the process, of course, is electricity — quite a lot of it, in fact.

Since electricity is not as stable in rural areas, in some cases none at all and we require this electricity in order to store our vaccines for an effective immunization. The WHO had to come up with other means of preserving our vaccine. So, for four decades now, immunization programs have been using insulated containers with frozen water packs to transport vaccines. As of 2013, there were 16 vaccine carriers prequalified by WHO with capacities ranging from 0.80 L to 3.61 L. These carriers are generally used for “last-mile” transport of vaccines. They can be carried by humans walking, on bicycles, or on motorbikes. For longer-distance transport, WHO had prequalified 21 cold boxes with vaccine capacities ranging from 6.3 L to 24.4 L. These cold boxes were used for transporting larger quantities of vaccine and generally need to be loaded on trucks for the journey. Both cold boxes and vaccine carriers required conditioned ice packs or cold-water packs to keep vaccines cool. However, if ice packs are not sufficiently conditioned (allowed to reach a stable temperature of 0°C, which is achieved when ice packs contain a mixture of water and ice) prior to being loaded, they pose a freezing risk to vaccines. Because many vaccines are freeze sensitive, including diphtheria-tetanus-pertussis, all diphtheria-tetanus-pertussis-containing multivalent vaccines, tetanus toxoid, diphtheria tetanus, hepatitis B, pneumococcal conjugate, rotavirus, human papillomavirus, typhoid, cholera, and inactivated polio vaccines, the risk of freezing has emerged as a serious issue. (Optimize, n.d.)

Between 1990 and 2010, a large number of temperature studies were conducted to examine vaccine supply chains in many different countries. A review article published in Vaccine found that among 35 of those studies, 34 found freezing temperatures in the cold chain, and 14 of those found more than 50 percent occurrence of freezing among recorded temperatures (Matthias, 2007).

As countries face the challenge of expanding the physical capacity of the cold chain, some have explored the possibility of increasing storage capacity at the point of use in small health centers. Refrigerators are often a poor technology choice at this level because the volume of vaccines stored can be very minimal and because it is very expensive to equip every small health center with vaccine refrigerators that need to be powered with electricity or gas and to be regularly maintained. However, highly insulated containers that can go for a week, two weeks, or even up to a month between ice changes could be a game-changing technology for vaccine storage at the health center level. If there is a convenient method for making or purchasing ice when needed, then vaccines can safely be stored at every health center at the proper temperature without reliance on electricity or refrigeration maintenance services. This can increase availability of vaccines at small health centers, which is especially important for the vaccines that are given immediately after birth, such as the hepatitis B vaccine to prevent mother-to-child transmission of hepatitis B and the tetatus toxoid vaccine to prevent neonatal tetanus.

2.2.2 Review on thermoelectric devices

Although vaccine coolers are designed to keep vaccines cold, a poorly designed apparatus can result in accidental freezing of vaccines so that sub-potent vaccines can sometimes be administered (Chen, & Kristensen, 2009). A 2007 study found that in vaccine reports tracked longitudinally, 75-100% of vaccines were exposed to freezing temperatures; the authors recommend improved cold-chain transport equipment as a solution (Matthias, Robertson, Garrison, Newland, & Nelson, 2007).

The cost of most vaccines today ranges from $3.50-$7.50 per administration (Gates, 2012), so wastage results in a considerable economic loss. Importantly, when vaccines lose potency, there is a loss of confidence in vaccine therapy (Larson, Cooper, Eskola, Katz, & Ratzan, 2011). Thus, reducing vaccine wastage while increasing potency will provide more effective immunization in the rural, developing world at a reduced cost per dose.

One way to address aspects of the wastage issue is the development of small coolers capable of transporting vaccines, maintained in the proper temperature range, from the regional health center to the distant client; this trip is termed the end stage of the cold chain. In thermoelectric module refrigerator mechanical parts such as, compressor, liquid coolant, condenser coil, evaporation coil and expansion valve are replaced by thermoelectric module. Ganesh S. Dhumal, P.A. Deshmukh, & M. L. Kulkarni designed a thermoelectric module refrigerator that was powered by a solar panel and a rechargeable battery. The experimental refrigerator contained a 0.5-liter insulated box, and two peltier plates with active heat sinks were utilized to dissipate heat from the peltier plate's hotter surface.

Solid-state thermoelectric cooling (Bell, 2008), employing the Peltier effect, offers an important alternate solution to temperature-regulated vaccine refrigeration (Ghosal, & Guha, 2009). For small loads, thermoelectric coolers offer significant advantages compared to the more conventional vapor-compression refrigeration: there are far fewer moving parts that may require maintenance, no risks of refrigerant leakage, and a lighter, more compact size.

A small battery-powered, thermoelectrically cooled vaccine cooler was the new solution to deliver safe vaccines. Several similar designs have been proposed previously (Chatterjee, & Pandy, 2003). By contrast to many previous studies that were conducted at room temperature, this cooler was tested with the express purpose of preserving vaccines at a high ambient temperature (37°C), typical of temperatures that would be encountered in the tropical, rural developing world. Our results suggest that vaccines can be maintained in a safe temperature range for ~ 10 hours at an ambient temperature of 37°C with one battery charge; this is enough time in a working day to deliver vaccines from a regional distribution center to clients for administration and for the return trip to the center. Since many parts of the rural developing world have sunny climates, the potential for solar panels affixed to the sides of the cooler to recharge the on-board battery was explored.

2.2.3 Review on solar-powered devices

A solar-powered vaccine storage is a refrigerator that runs on solar-generated electricity. In hot locations, solar-powered refrigerators can keep perishable commodities like meat and dairy cool, and they're also used to keep vaccines at the right temperature to minimize spoiling. Solar-powered freezers are more likely to be employed in underdeveloped countries to help alleviate poverty as electrical sources might be unpredictable. In this case, Palash Nakhate, Niraj Pawaskar, Purva Vatamwar , & Saurabh Kalambe worked on a solar-powered vaccine storage system that can assist in overcoming issues such as electricity disruptions and mobility. This overview depicts the safe storage of vaccines and other medical and home items in a cold environment without jeopardizing their quality. The system will be powered by a solar panel for power, a battery for storage, and an AT MEGA 328 processor and other components. The proposed system will assist the user or owner in maintaining a cool temperature for the product's preservation. The sun's energy is captured and stored in the system for future use. The system is portable, allowing users to take it with them. The system is also designed to operate on a single phase 230-volt supply.

2.2.4 Review on Intelligent solar-powered immunization vaccine storage system

Solar energy has recently become quite appealing for cooling reasons. It can provide a cheap and clean source of electricity for cooling and refrigeration all over the world. Solar refrigeration technique takes energy from the sun's radiation and uses it to chill things down. This approach is a suitable alternative for pharmaceutical and vaccine storage facilities where the electricity supply is unpredictable but there is enough sunlight. It can also be used in places that aren't connected to the grid.

Maintaining the proper temperature for heat-sensitive vaccinations is critical, but it can be challenging in locations with limited or no electricity, as well as frequent or long-duration power outages, making grid-powered cooling impractical for vaccine storage. Refrigerators powered by gas or kerosene, often known as "absorption refrigerators," have long been thought to be the best alternative in locations where electricity is inconsistent. These technologies, however, have a few disadvantages. Solar refrigerators were first offered in places without electricity in the 1980s as a remedy to the issues with gas and kerosene refrigerators. The refrigeration process involves extracting heat from a specified surrounding space in order to reduce its temperature below that of the surrounding environment. Instead of employing the vapor compression or absorption cycles, the goal is to use thermoelectric effects to provide cooling.

2.3 Summary of Findings

As our aim is to maintain the cold chain system, which is the means for storing and transporting vaccines in a potent state from the manufacturer to the person being immunized at a temperature of 2–8°C. Proper vaccine storage and handling are important factors in preventing and eradicating many common vaccine preventable diseases. Yet, each year, storage and handling errors result in revaccination of many patients and significant financial loss due to wasted vaccines. Failure to store and handle vaccines properly can reduce vaccine potency, resulting in inadequate immune responses in patients and poor protection against disease. Patients can lose confidence in vaccines and providers if they require revaccination because the vaccines they received may have been compromised. Proper storage and handling begin with an effective vaccine cold chain.

If the cold chain is not properly maintained, vaccine potency may be lost, resulting in a useless vaccine supply. Vaccines must be stored properly from the time they are manufactured until they are administered. Potency is reduced every time a vaccine is exposed to an improper condition. This includes overexposure to heat, cold, or light at any step in the cold chain. Once lost, potency cannot be restored.

Therefore, we need storage systems that prevents freezing occurrences in vaccine supply chains. In addition to freeze prevention, there is a need for technologies that can transport larger volumes of vaccines and make more efficient use of transport volume. We also need a storage system that can last more than 10 hours in ambient temperature, so this can give us enough time to travel to rural areas without compromising the vaccine

Table 2.1: Summary of past works

S/N	Year Published	Title of work	Author	Findings
1	2013	Savsu Nano-Q Insulated coolers	The Path	It's stationary passive cooling for storage. It has a six-to-eight-day cold life depending on the ambient temperature and the vaccine storage capacity is 6 L. It was evaluated in Vietnam but the challenge was that sometimes this vaccines experience freezing and the cooling holder had no LCD to monitor the temperature.
2.	2014	Solid state thermoelectric storage system	Ganesh S. Dhumal, P.A. Deshmukh, & M. L. Kulkarni	This solid-state thermoelectric vaccine storage system was able to eliminate the issue relating to freezing and lasted 10 hours during transportation. This 10 hour was the estimated time it would take them to leave the health centers and go to the smaller health centers to administer the vaccines to the patients.
3.	2015	Solar panel thermoelectric storage system	Palash Nakhate, Niraj Pawaskar, Purva Vatamwar, & Saurabh Kalambe	It was able to solve the challenge in locations with limited or no electricity, as well as frequent or long-duration power outages, which made grid-powered cooling impractical for vaccine storage.

4.	2016	Solar powered coke fridge for storing vaccine	Anderson	This storage device was built like a coke fridge. It was used to store vaccines but the only disadvantage is that, the fridge was not a portable system, therefore it will be stationary.
5.	2018	Solar powered Refrigeration system	Nasa	Just like every other solar powered refrigeration. The main aim is to eliminate the reliance on grid electricity. This system also was able to achieve that. This system did not require any battery. It was powered directly from the solar panel. It is also a stationary system and can't be moved about easily.

In this paper, work is focused on the designing of the cold box which is capable to maintain a temperature range from 2.0 -8.0 C constantly using Peltier-based thermoelectric chip, specific structural design obtains through calculation and technological based solutions.

Another crucial characteristic of this instrument is that it delivers an optimal power usage forecast to keep the ideal vaccine storage in precise temperature range in presence of limited power supply from environment.

Due to a collective action of the phase change material and thermoelectric device, the temperature inside the box is will be maintained. The details of the temperature settings will be accessible and visible on the device screen. This box is an efficient carrier as it will aid in tracing, automated settings, consistent temperature, carrying and packaging which will be an alternative to the currently available techniques in practice.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This chapter will talk about all the materials we used in building this project and the methods we adopted to make this project work. We are going to discuss everything in detail such as the mathematical modeling and selection of the thermoelectric module (Peltier module); cooling load calculation of designed temperature; solar panel selection, sizing, battery sizing and selection; and temperature controller using Arduino microcontroller.

3.2 Materials Used

The materials used are divided into two categories namely; the hardware requirements and the software requirements. The hardware requirements are all the physical electronic components used in building the vaccine storage system while the software requirements are the software applications where the code was designed and implemented with.

3.2.1 Hardware Requirements

A. Photovoltaic (Solar panel)

The photovoltaic cell in a solar panel turns light energy into electrical energy. The output voltage of a solar panel was determined by the amount of light falling on it, and it was used as a vital source of energy in this project. The photovoltaic cell, which is made out of solar panels, uses a unique process to convert photons to electrons and produce a current.

Photovoltaic cells are made of semi-conductive materials like silicon and receive their energy from the sun. When this happens, photons from the sun collide with electrons in the photovoltaic cell's substance, allowing an electrical current to flow. Within each cell, an electric field is employed to control the flow of electrons in a specific direction. It can be used as a power device while these electrons come through a metal contact placed on the photovoltaic cell.

Fig 3.1: Solar Panel

Solar cells have positive and negative contacts. If the contacts are connected with a conductive wire, current flows from the negative to positive contact which a single photovoltaic cell can deliver approximately 1 to 2 watts of electricity. To extend the yield of power, several photovoltaic cells are electrically connected to create a photovoltaic module and these modules are further electrically connected to make a photovoltaic board photovoltaic array. The number of modules associated to make a cluster depends on the sum of solar electrical energy required.

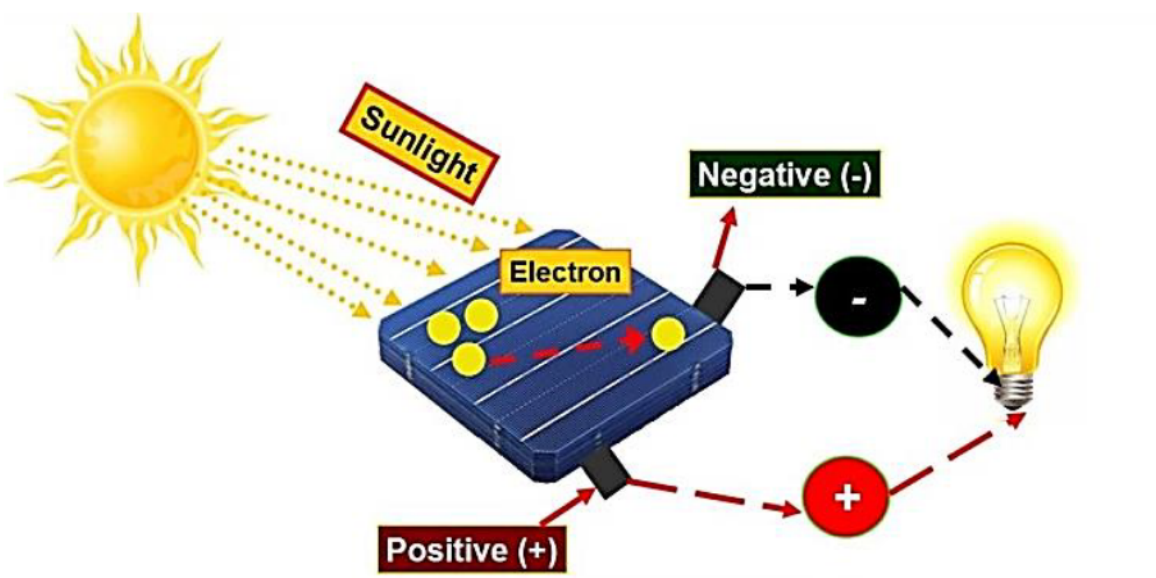

Fig 3.2: PV cell working principle

How we choose our Solar PV

CALCULATING FOR SOLAR PANEL RATING

Recommended Solar panel rating = (Battery bank capacity ÷ Daily sunlight hours) ÷ Unit solar panel wattage

For battery 180AH 12V

Battery bank capacity = 12 x 180 = 2,160WH

Solar panel rating = (2160 ÷ 7) ÷ 100

= 3.08 ≈ 300W solar panel

B. Thermoelectric Kit (Peltier module, heatsink and fan)

A thermoelectric kit is made of the main Peltier module, heat sink and fan. This thermoelectric (TE) cooler also known as thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat compressor. By applying a low voltage DC power source to a TE module, heat will be generated in the module from one side to the other. One module face will be cooled while the opposite face at the same time is heated. if this phenomenon is reversed a change in the polarity of the applied DC voltage will cause heat to be moved in the opposite direction. Therefore, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications. The principle of thermoelectric refrigeration is known as “Peltier Effect.”

Basics of Peltier Effect

A voltage difference is produced when two wires of different materials are joined together at its end and heated at one its end, this phenomenon was discovered by Thomas Seeback in 1821 and is known as the “Seeback Effect.” The two main applications of Seeback effect include temperature measurement and power generation. Fig 3.3 shows a Seebeck effect consisting of two wires of different metals, connected in a closed circuit. If one end is heated a current will flow continuously.

Thirteen years later Jean Charles Anthanase reversed the flow of electrons in Seeback's circuit to create refrigerating effect. This phenomenon is known as "Peltier Effect". This idea forms the basis for the thermoelectric refrigerator, which is what we are using for this project.

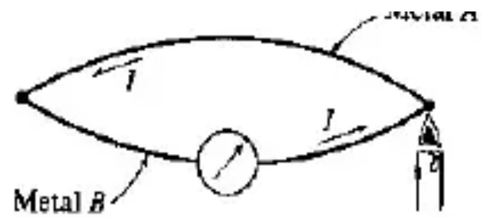

Fig. 3.3 Seeback Effect

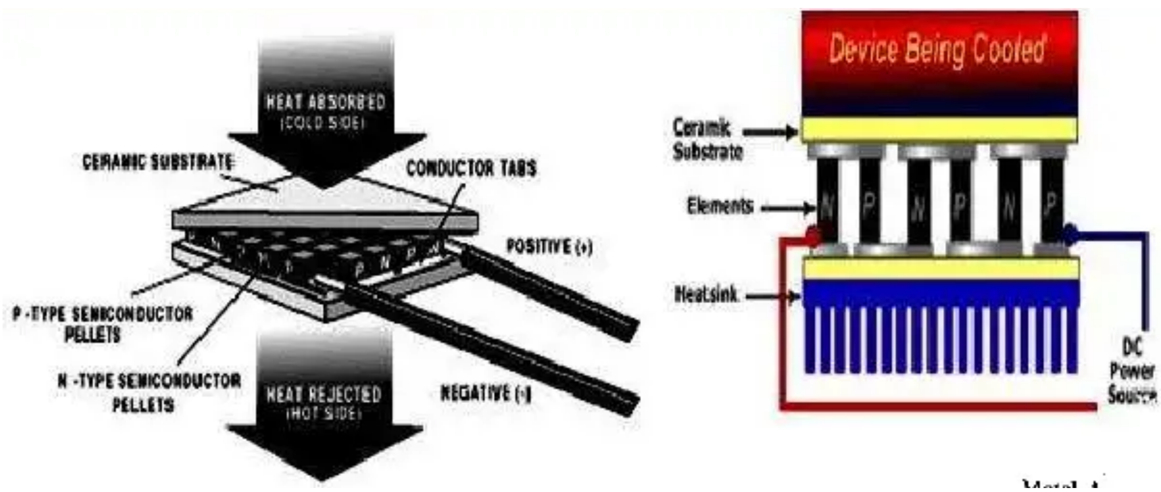

Fig. 3.4 Thermoelectric module assembly

How it Works Compared to Mechanical Refrigerator

Thermoelectric coolers and mechanical refrigerators are governed by the same fundamental laws of thermodynamics and refrigeration systems. In a mechanical refrigeration system, a compressor raises the pressure of a liquid and circulates the refrigerant through the system. Within the evaporator the refrigerant boils and in the process of changing to a vapor, the refrigerant absorbs heat causing the freezer to become cold. The heat absorbed in the freezer is sent to the condenser where it is ejected to the environment from the condensing refrigerant. (Ferrotech, 2016)

In a thermoelectric cooling system, a doped semiconductor material replaces the liquid refrigerant, the condenser is replaced with a finned heat sink and a power source replaces the condenser. The Seebeck and Peltier, together with several other phenomena, form the basis of functional thermoelectric refrigeration.

C. Microcontroller (ATMEGA 328P)

The microcontroller used to implement the project is ATMEGA328P. The reason for using this microcontroller, is because it bears the whole features needed for the project which include: Serial port, digital I/O, up to 2234B of RAM, 32KB of ROM, 1B of EEPROM and Speed of up to 16MHZ. The above listed features made the microcontroller worthy of the design. Below is the circuit diagram of the microcontroller board.

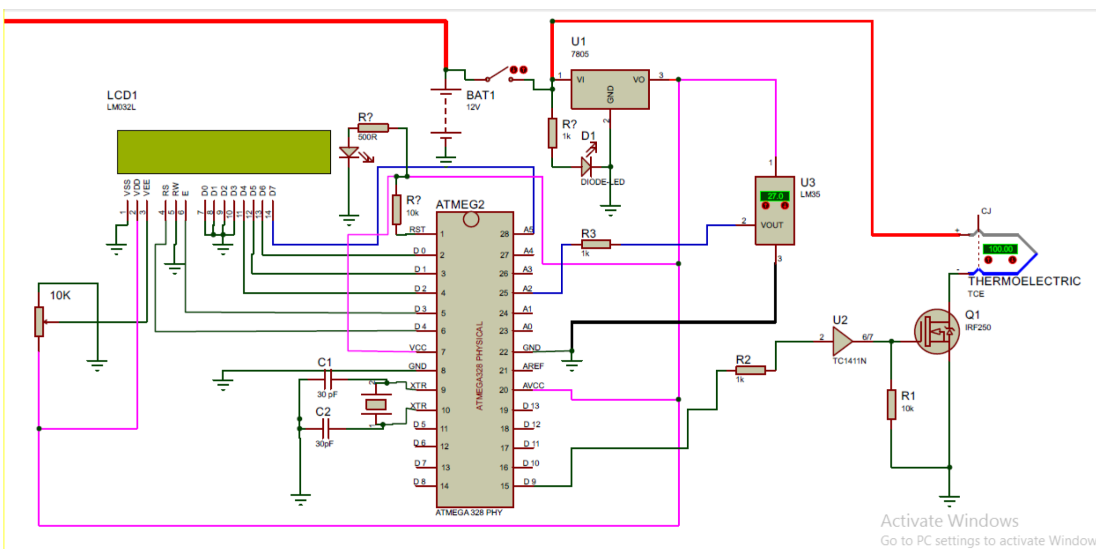

Fig 3.5: The Microcontroller Board

The Connections on the Microcontroller board

The microcontroller board consists of the microcontroller, crystal oscillator circuit, the reset resistors, pull up and pulldown resistors, also attached to the microcontroller is the fingerprint module, LCD and the temperature sensor.

D. LCD Display

A liquid crystal display (LCD) is an electrical display module that produces a visible image using liquid crystal. The 162 LCD display is a fairly basic module that can be found in many

DIY projects and circuits. The 162 refers to a two-line display with 16 characters per line. Each character is presented in a 577-pixel matrix on this LCD.

E. Energy Storage (Lithium Battery):

Solar energy has to be stored for use, if the sun is not shining. To store this energy battery is used. We used a 12V lithium battery because it portable and lighter to carry around instead of the 12V lead acid dry battery. There are two types of batteries which is the primary battery and secondary battery. The basic difference of this battery is; the primary battery is not rechargeable its one-time use and has a short life but the secondary battery is rechargeable and has long time usage. Therefore, the battery used in this project is a secondary battery.

How we choose the battery we used

The power supply

Table 3.1 Total power consumption of the designed system

DEVICE	VOLTAGE	CURRENT	POWER
THERMOELECTRIC	12V	10mA	120W
TEMPERATURE SENSOR	5V	20mA	0.1W
LED INDICATOR	2V	10mA	0.04W
ATMEGA 328P	5V	16mA	0.08W
Total			120.22W

Since the net load of the system circuit is 120.22W the power supply must not be less than 120.22W.

Calculating for the power bank

Expected backup time 18 hours

Battery bank capacity = Load power x Expected run time

120.22 Watts X 18 hours = 2,163.96 WH

Since system voltage is 12V

Required power banking in AH = 180.3 ≈ 180AH 12V battery

= 180AH Battery

F. Charge Controller

A charge controller sometimes called a photovoltaic controller or battery charger. The essential work of a charge controller is to avoid overcharging of the batteries. Most have a low voltage disengage that avoids over-discharging batteries.

G. Temperature Sensor

The temperature sensor in this project is an electronic component that senses the temperature of the thermoelectric device, which in turn will be displayed on the screen for the users to know the temperature rating of their vaccine and decide if there is a problem or not. The temperature sensor we used here is a DHT-11 sensor.

3.2.2 Software Requirements

These includes all the software we used from the inception of the project to its completion.

A. Operating System

An operating system (OS) is system software that manages computer hardware, software resources, and provides common services for computer programs. The OS manages a computer's resources, especially the allocation of those resources among other programs. Typical resources include the central processing unit (CPU), computer memory, file storage, input/output (I/O) devices, and network connections. Management tasks include scheduling resource use to avoid conflicts and interference between programs. Unlike most programs, which complete a task and terminate, an operating system runs indefinitely and terminates only when the computer is turned off.

Hence, the PC we used for the project runs on Windows 10 OS with a 64bit core i3 4th Gen - (4 GB/1 TB HDD/DOS) G50 70 Processor Variant. 4030U; Chipset. HM87

B. Proteus

Proteus is a simulation and electronic design development tool developed by Lab Center Electronics. It is a very useful tool as it ensures that the circuit design or firmware code is working properly before you begin to physically work on it.

It has an extensive number of components in its library which can be used to virtually design your circuit. The designs you make can be easily compiled and debugged through Proteus's virtual meters (voltmeter and ammeter), oscilloscope, serial monitor, and more.

We used Proteus for Arduino project simulation because of its extensive collection of libraries. However, it is not only limited to simulation — you can also make PCB designs with it. After our simulation was confirmed alright, we went ahead to build our project on a breadboard first.

C. Arduino

The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. This software can be used with any Arduino board. Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments.

For this project, once we were done writing our code using C++ in the Arduino IDE, we debugged it to check for errors and when it was all correct. We transferred our program to the Arduino board with our microcontroller on it.

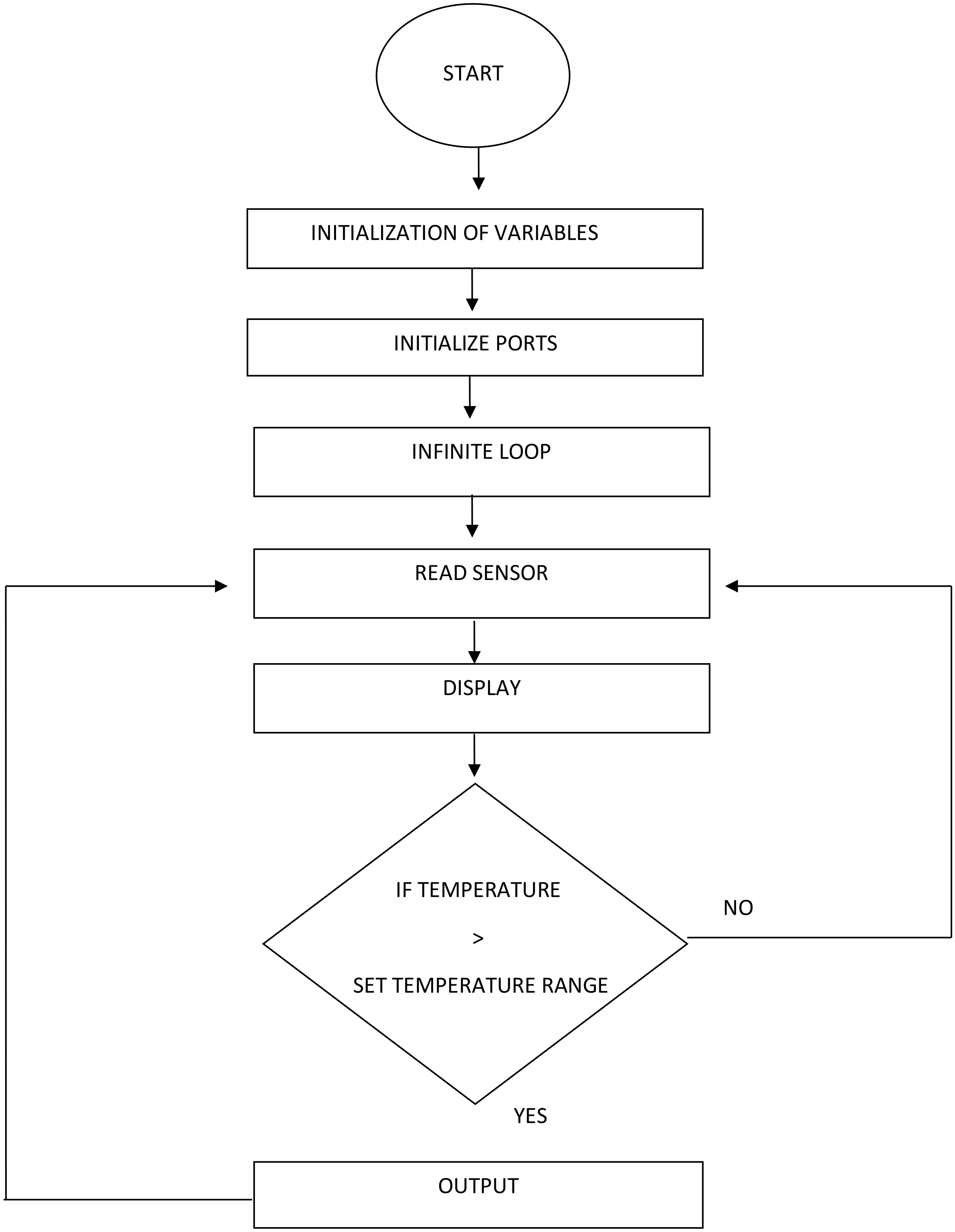

FIG 3.6: FLOW CHART OF THE SOFTWARE

3.3 Methods

The method used in this thesis to accomplish the required task is shown in Figure 3.5. The closely related papers and literature were reviewed. Then the necessary data used throughout this research are collected and analyzed. This research could follow this method to solve the problem state in chapter one.

The purpose of a solar panel of this system is to deliver electrical power to the system. The solar panel power is depending on the irradiation of the environment. So, it will fluctuate according to the variation of the irradiance. The Peltier module needs a regulated DC power supply. To regulate the power, solar panel perturbs and observer MPPT technique is used. The heat sink and the fan are integrated into the Peltier module to reduce the difference in temperature of each side of the module. Together the MPPT, heat sink, and fan are helping the system achieve maximum COP.

Giving a cooling effect is not enough for this system, the temperature inside the mini-refrigeration system must be regulated. There is a close loop operation available in the temperature controlling process. The microcontroller takes the action of the temperature regulation process in this system.

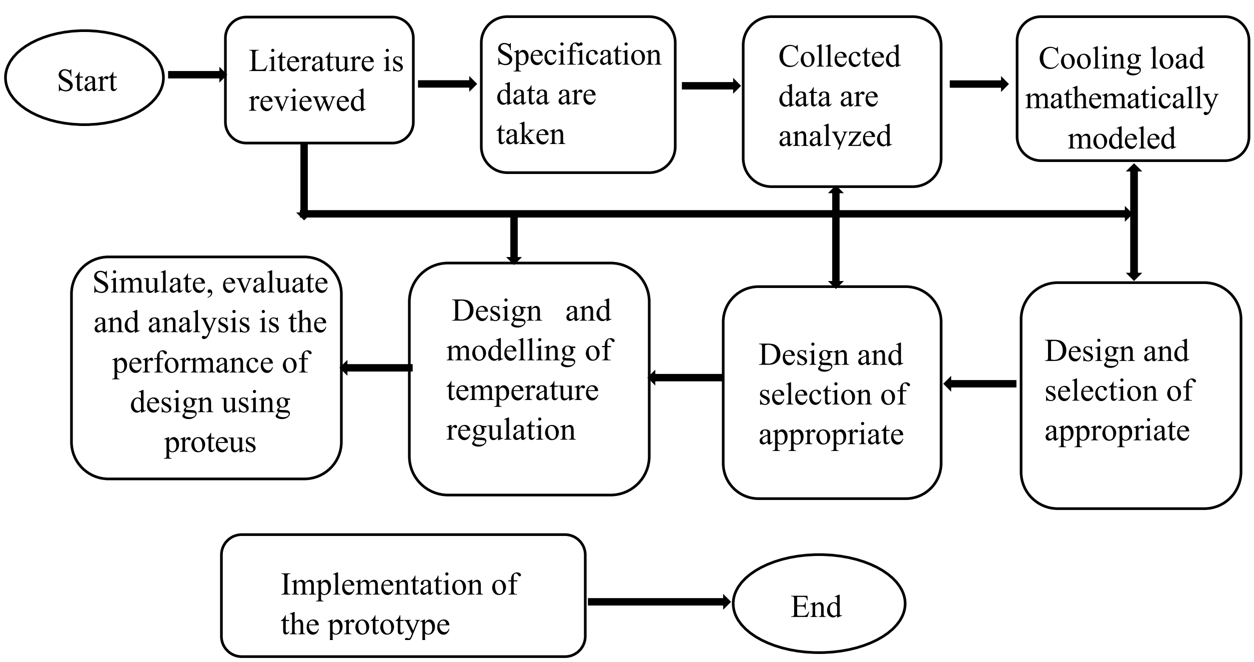

Fig 3.7 Methodology

A temperature sensor called DHT- 11, play a vital role in the regulation process, it senses the environment and gives the feedback signal to the microcontroller. This microcontroller operates the refrigeration temperature according to the required range. The control action includes the on/off control of the Peltier module and fan, the LCD temperature display for human interaction, and to show the status of the temperature.

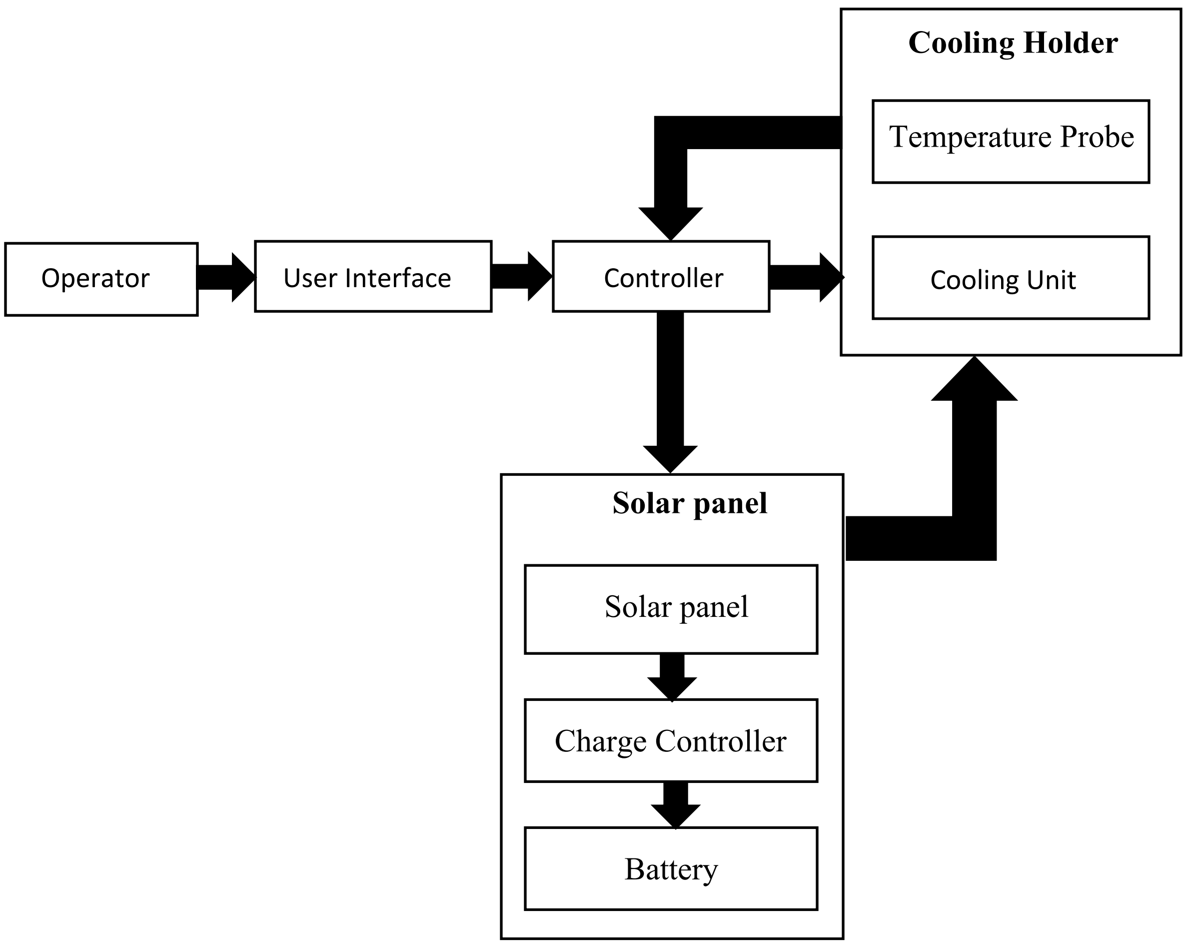

Fig 3.8 Block diagram of the proposed system

Operator

The operator will interact with the user interface. Information like the desired temperature will be inserted into the user interface by the operator.

User interface

The temperature and energy consumption will be displayed on the user interface. The user will also be able to set the temperature on this interface.

Controller

The controller will receive information from the user interface, solar power system and the temperature probe. This information will be used to control the temperature by controlling the status of the cooling unit. The controller will also send information like the temperature and energy consumption to the user interface.

Cooling holder

The cooling holder will isolate the vaccines from the ambient temperature. The cooling unit, temperature probe, controller and user interface will be mechanically connected to the cooling holder.

Temperature probe

The temperature probe will capture the temperature inside the cooling holder and send this information to the controller.

Cooling Unit

The cooling unit will be responsible for maintaining the required temperature inside the cooling holder. The cooling unit's status will be determined and controlled by the controller.

Solar Power system

The solar power system will supply the necessary power to the vaccine cooling holder.

Solar panels

Solar panels will be used to capture renewable energy from the sun.

Charge controller

A charge controller will be used to determine the maximum power point of the electricity supplied by the solar panels.

Batteries

The energy supplied by the solar panels will be stored in the batteries

3.4 Circuit diagram

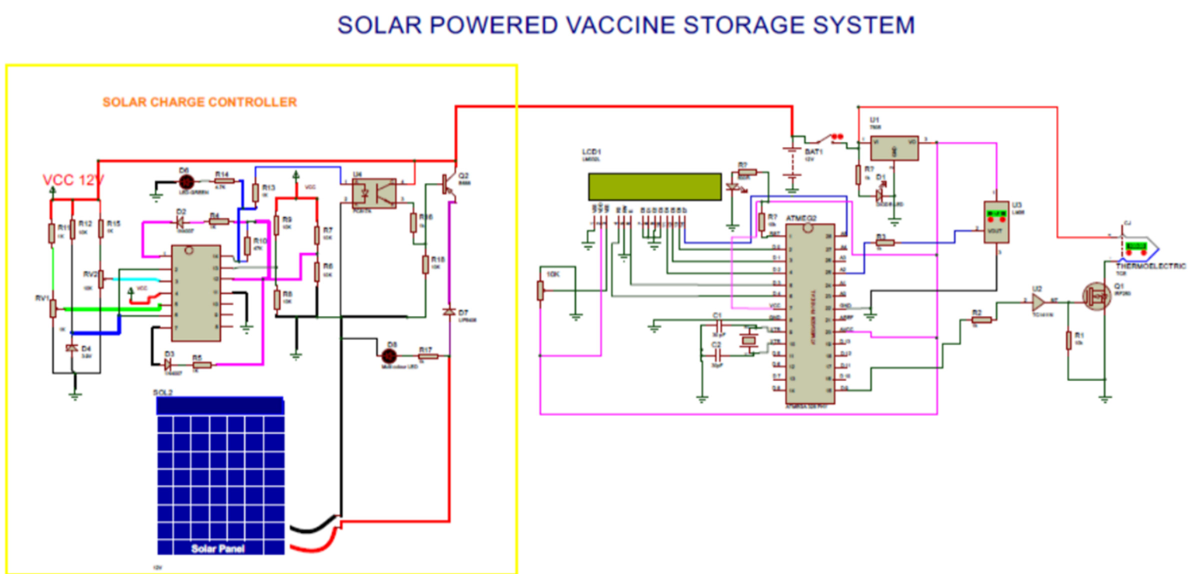

Fig 3.9 Circuit diagram of the proposed system

This is the circuit diagram we used for this system. We researched on each component, starting from how LCD and microcontrollers are connected. Looking at how previous people connected theirs, and with a lot of other reference articles, we were able to create a working connection after several tries. Then according to ATMEGA 328P datasheet, we were able to know where to connect other components to the microcontroller. When we were able to create the full circuit diagram, we tested in on proteus first before we started building.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Results

After the design and implementation phase, the system built had to be tested for durability, efficiency, and effectiveness and also ascertain if there is need to modify the design. The system was first assembled using a breadboard. All components were properly inserted into the breadboard from whence some tests were carried out at various stages. The components were tested before being implemented on Vero board while the programming was simulated with the circuit design using PROTEUS; a virtual environment used in replicating the real life environment before implementation. The implementation and testing phase are divided into two sections which are the hardware section and the software section. Bread boarding of the peripheral hardware, development of microcontroller software, and final debugging and testing of the circuit board for the microcontroller and peripherals all require a development environment which was simulated with PROTEUS. To ensure proper functioning of components' expected data, the components were tested using a Digital Multimeter (DMM). Resistors were tested to ensure that they were within the tolerance value. Faulty resistors were discarded. The 78LS05 voltage regulator was also tested, the resulting output was 5.02v which is just a deviation of 0.20v from the expected result of 5.00v. Therefore, the expected result for this project was achieved.

4.1.1 Testing of the Circuit on a bread board

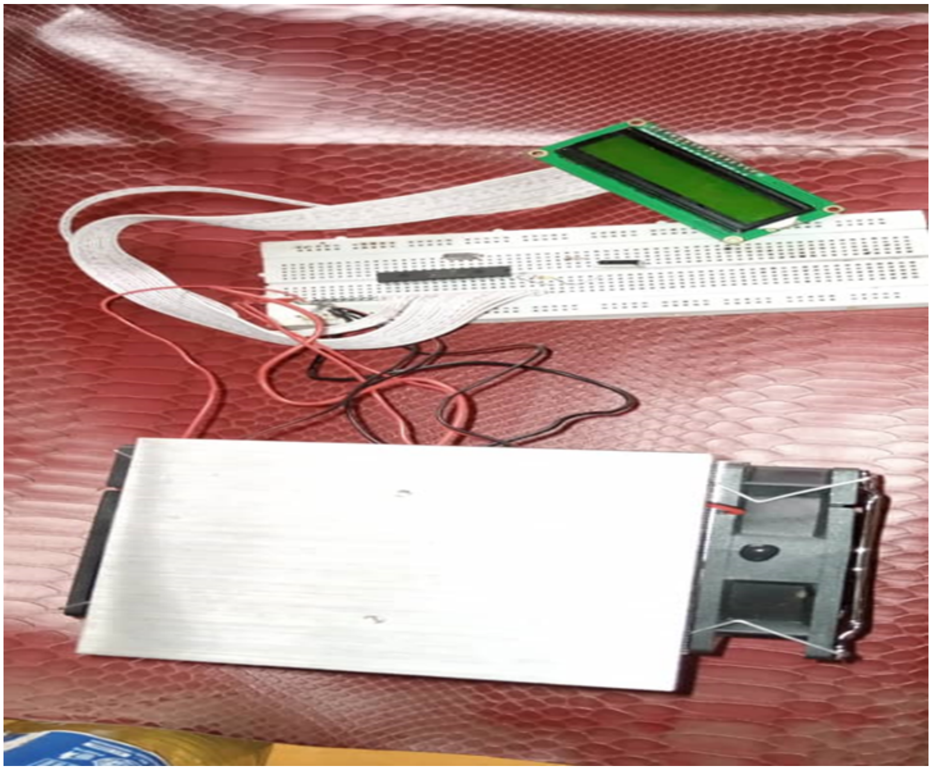

Fig 4.1: The testing on a bread board

The testing of the system circuit was first done on bread board using Peltier module, fan and LCD as an output. The LCD displayed the current temperature and the status of the mini-refrigeration system. The equipment we used in the prototype design is listed below.

- Temperature sensor
- Peltier module
- BLDC fan
- LCD
- Heat sink
- Ice-box
- Connecting wires
- Arduino uno
- 12v power supply

Figure 4.2: Building on a vero board

4.1.2 Modelling of the design

Fig 4.3: Three pictures showing the model of the proposed system

Once it was confirmed working and everything was working to our satisfaction. We headed to the next step which is the final fabrication. The cooling holder was then fitted into a vertical cupboard constructed with wood, to look like a fridge. The inside of the cooler was then covered with aluminum foil for effective cooling. The battery is fitted down under the cupboard, which is detachable.

Fig 4.4: Final Fabrication of the proposed system.


Temp:29.00°C
Energy: 48%

4.2 Discussion

The Vaccine cooling system is evaluated and tested to ensure that the objectives of this project are achieved. The most important objective of this project is to ensure that the vaccines stay in the cold chain. The equipment used to test the Vaccine cooling system included a DC power supply with a constant voltage of 12 V, a multi-meter, the lm35 temperature sensors.

The system was tested to evaluate the temperature change in the cooling holder, the time required for the temperature change and the energy usage of the system. The lm35 temperature sensor has been validated in previous research, therefore, there is no need presenting the validation results in this paper once it was confirmed to be working effectively by verifying the temperature values using an external equipment.

The temperature of the cooling system without a load over a period of 100 minutes. The figure shows the time that is required by the system to reach a temperature of 3 °C. At 3 °C the system was switched off to measure the time the system will keep its temperature and stay in the required temperature range of 2 °C to 8 °C.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The testing of the prototype was done and observations were made. The minimum temperature reached was 7˚C. All the values of the sensors are collected and are sent to microcontroller. The temperature reading was observed on the screen of the LCD. The portability of the box will aid easy movement when using the vaccines at vaccination sites. Use of more thermoelectric module will increase the efficiency of cooling and storing capacity can be further increased.

This work is very beneficial for proper cold chain storage. It can also be employed in a variety of industries by adjusting the chilling unit's temperature range, such as in rural areas where dairy products require special attention, or near the beaches where marine foods must be transported.

Finally, we conclude that other refrigerators are less reliable than this solar-powered vaccine storage. It is both cost-effective and environmentally friendly, which is the most desired criterion in today's world.

5.2 Recommendation

Solar power nowadays is playing a major role in meeting the energy requirement of our country. Though this mini-refrigeration system we created has been able to solve the statement of problem listed in this paper and it is working satisfactorily to its full capacity. There are still changes and improvements we recommend for anyone who will handle this project in the future. The change can be done in this fridge to make it more user friendly and classy. The change we recommend is that; the system should be built in such a way that it accommodates grid electricity along with solar electricity. In this way rural areas with little electricity can still make use of electricity no matter how small the period might last. Especially, during rainy season where sun energy is lesser.

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APPENDIX

Arduino Software Code

```
#include <LiquidCrystal.h>
const int sensorpin = A0;
const int output = 9;
float reading;
float duty;
float temperature;
float voltage;
float mapTemp;
const int rs = 3, en = 4, d4 = 5, d5 = 6, d6 = 7, d7 = 8;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
byte degree[8] = {
  0b00111,
  0b00101,
  0b00111,
  0b00000,
  0b00000,
  0b00000,
  0b00000,
  0b00000
};
void setup() {
  lcd.createChar(7, degree);

  lcd.begin(16, 2);
```

```
lcd.print("vaccine storage");
}
void loop() {
  reading = analogRead(sensorpin);
  voltage = reading * (5000 / 1024.0);
  temperature = voltage / 10;
  mapTemp = temperature;
   duty = map(mapTemp, 2, 8, 0, 255);
 if (temperature < 2) {
    analogWrite(output, 0);
  }
 else if (temperature > 8) {
    analogWrite(output, 255);
  }
  else {
    analogWrite(output, duty);
  }
    lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("temperature:");
  lcd.setCursor(0, 1);
  lcd.print(temperature);
  lcd.write(7);
  lcd.print("C");
delay(1000);
}
```