PROPOSAL REOPORT FOR THERMOELECTRIC REFRIGERATOR POWERED BY PHOTOVOLTAIC MODULE AND INCORPORATING IOT

EXECUTIVE SUMMARY

The world's demand for energy is uninterruptedly increasing each day and over utilization of non renewable energy sources to power refrigeration system have cause various ecological issues such as dangerous atmospheric temperature deviation, corrosive downpour, ozone layer depletion, and environmental changes.

Utilising renewable energy technologies might lessen these catastrophes; as a result, thermoelectric refrigerators are becoming more popular because of their straightforward design, small size, and low DC voltage requirement.
Regular vaccination programs are a prevalent occurrence in rural communities, which are characteristically known for having unreliable grid electrical power supplies. Small populations make it impossible to employ all of the vaccines that are released, and some of them typically get spoiled. Its special qualities of not having moving parts, no greenhouse fluids, and no need for pipes or mechanical compressors in its cooling systems make it imperative to use thermoelectric refrigerators powered by solar photovoltaic modules and integrating IoT for vaccine distribution and preservation in rural areas where grid power supply is virtually unreliable or nonexistent.

The ultimate strategic goal of this research project was to create a thermoelectric refrigerator that is powered by a solar photovoltaic module and integrated with the Internet of Things. This refrigerator will be affordable, require less maintenance expertise due to its technology literacy, and measure design parameters like battery level, temperature, and humidity levels in real time for both on-site and off-site visuals.

Nigeria has roughly 1.4 healthcare facilities per 10,000 people, with about 85.3% of them being primary health care facilities (PHCs).Public (PHCs) in Nigeria numbers is about 28, 036, of these publicly owned PHCs, it's estimated that 33% are functional. Among the functional PHCs 33% - 35% PHC facilities are open 24/7, around 40% do not have any access to electricity at all. For the PHCs with electricity, the supply is often most t unreliable, many get 6 hours of power per day on an average. Solar is used in less than 20% of PHCs. Electrification interventions are not evenly distributed. There is a concentration of projects in South-South, South-East, and South-West geopolitical zones (SEforALL, 2021).

Vaccination is a critical health care service delivery to both infants between age zero to ten years and adults, for adults vaccination can prevent asexually transmitted disease and also can be immune booster for pandemic virus like we saw during Covid 19 pandemic

Problem statement and Justification

It is impossible to overstate the importance of a low-cost, non-conventional compressor refrigerator system that is portable and useful, as it will lessen or do away with the significant reliance on fossil fuel generators to power ice block making machines that create ice blocks for cooling storage devices during vaccine preservation and distribution because of the unreliable or nonexistent grid power system in rural areas.

Conventionally, primary health care centres utilises grid AC power system or alternatively switch to fossil fuel generators to power AC compressor refrigerators to cool vaccines due to unreliable grid system or in some locations where there is total absence of grid power. This increases the cost of running primary health centres and also impacts on service delivery.

The introduction of thermoelectric refrigerator powered by photovoltaic module and incorporating IoT will be a paradigm shift due to the following reasons:

(i) Rural areas with unstable grid systems or complete lack of grid power, a thermoelectric refrigeration system driven by a photovoltaic module with Internet of Things integration will ensure vaccine integrity during preservation and field distribution.

(ii) Thermoelectric refrigerator will utilise abundant solar irradiance in areas of deployment during utilization as the device runs on low DC voltage.

(iii) When the thermoelectric refrigerator powered by a solar module with an Internet of Things technology interface is deployed to the field, the device delivers real-time remote and on-site visuals of the battery level, temperature level, and humidity level.

(iv) The solid state refrigerants utilized by the thermoelectric refrigerator, makes the device to have minimal maintenance and less complexity in it operations.

(V) Using a thermoelectric refrigerator with a photovoltaic module will raise awareness about the use of clean energy, cut down on carbon-emitting equipment, and lower operating costs in basic healthcare facilities because of the refrigerator's cost-effectiveness.

The utilisation of vaccine carrier boxes which solely depend on ice block produced by conventional AC refrigerator by either unreliable grid power system or alternatively with diesel generator will which adds to carbon emissions and high running costs of the primary health care facilities (PHC). Also in rural communities where there is nonexistent of grid power or unreliable grid power, vaccine box with 5 different vaccine (measles, DPT,BCG,polio and IPV)10 packs each making a total of 50 vaccines which is accompanied by five health care workers namely: a nurse, a community health worker, a record officer, an environmental officer and a supervisor. The implication of this is that deploying two hundred and fifty vaccines will require five (5) vaccine box carriers which depends on ice blocks and twenty five (25) health care workers, but the utilisation of a single thermoelectric refrigerator which has a minimum of twenty litres volume capacity will carry six hundred vaccines with five health care workers. These will ultimately safe cost of vaccine campaign in terms of health care workers remuneration during vaccination service delivery.

Objectives of this research work

The factors that careful guided the objectives at the conceptual stage of this research work are:

- Present energy situation and refrigeration system in primary health care centers located in remote rural areas
- Technical expertise in rural areas
- Solar irradiance condition in rural areas in Nigeria were the device will be deployed
- Internet network coverage in rural areas in Nigeria were the device will be deployed

- ❖ Durability of embodiment of the device that will with stand environmental condition

The objectives of the research work are state below:

1. Design calculations for the thermoelectric refrigerator's powering system, including solar PV, charge controller, battery sizing, and simulation
2. An electronic circuit designed using programming code which enables a microcontroller act as a central processing unit to retrieve parameters, such as: battery level, temperature and humidity level of the refrigerator when deployed for vaccine preservation and distribution in the field.
3. In the design an LCD is interfaced with the output pines of the microcontroller for the purpose of displaying battery level, temperature and humidity level of the refrigerator when deployed in the field in digital numerical values for the health workers observation and monitoring.
4. The design will make use of internet of things (IoT) technology since the thermoelectric refrigerator, which is powered by a solar photovoltaic module and incorporates IoT, represents a paradigm leap from the traditional compressor refrigerator. When used to preserve and distribute vaccines, this will enable off-site real-time visuals of the refrigerator's temperature, humidity, and battery level in the form of digital numeric values and a continuous straight line graph that is shown on the LCD once every minute with the help of a Wi-Fi module. Additionally, these data will be automatically stored in an Excel file format on a dedicated server.
5. Thermoelectric refrigerator powered by solar photovoltaic module and incorporating IoT is supposed to be used in remote rural areas, consequently in the circuit design solar module, charge controller and battery bank which will achieve uninterrupted stable low DC power source is considered and interfaced with the input pins of a microcontroller for the purpose charging the backup battery and device utilisation during days of autonomy. This design consideration makes it possible for the refrigerator to operate seamless on a low DC voltage independent of grid electricity and not susceptible to electrical shocks when moving the refrigerator.
6. The programming codes created for the device's electronic circuitry and virtual implementation will be achieved with local content. The refrigerator's cooling mechanism used solid state micro components such a Peltier refrigerant module and heat sink, which allowed the device to operate without the need for moving parts, compressors, or coolant lubrication.
7. In the design, reinforced composite plastic embodiment that is water proof is utilized to enclose the entire circuitry hard ware, battery bank and Solid state miniature component such as Peltier refrigerant module and heat sink .This makes it possible to achieve light weight, thermoelectric refrigerator powered by solar photovoltaic module and incorporating IoT for vaccine preservation and distribution in the field.

Materials and Methods

Figure Fig 1 shows the block diagram of the device below depicts the block diagram of the thermoelectric refrigerator powered by solar photovoltaic module and incorporating IoT, with the signal flow across the devices various parts. The power supply section 116, the microcontroller unit 118,temperature and humidity unit 120, the peltier unit 121, buzzer unit 122, and peltier cooling unit 123, which makes up the thermoelectric refrigerator powered by solar photovoltaic and incorporating IoT. Wi-Fi module unit 119 and LCD unit 117 are two further units. The power line 112 is represented by solid line while the signal flow 115 is represented by broken lines. The following subsection provides design description for each unit.

The power supply section 116 is made up of the solar panel unit 110, charge controller unit 111, battery bank 113 and voltage regulator 114 which provides the electrical energy needed by the thermoelectric refrigerator powered by solar photovoltaic and incorporating IoT for an uninterrupted power supply when the thermoelectric refrigerator is functioning. Consequently, the device is powered using the abundant energy of the tropical African sun that is solar photovoltaic.

The microcontroller unit 118 is made up of Arduino promini. It serves as the heart of the thermoelectric refrigerator. All signals from the different units are fed into the microcontroller for processing and further transmission to the other units. The set of instructions used to program the microcontroller was carried out using C++ programming language.

The temperature and relative humidity unit 120 utilized one sensor which jointly measure and record the temperature and humidity of the thermoelectric refrigerator at same time, when the thermoelectric refrigerator is deployed to the field. It has the advantage of space economy as against using separate sensors for both parameters.

The peltier unit 121, is composed of many pairs of N-type and P-type semiconductors which works by using electrical energy to transfer heat from one side of the module to the other therefore creating a hot side and a cold side which ultimately results in the cooling of the refrigerator without coolant fluid or refrigerant.

In the Peltier unit, the N-type and P-type solid state semiconductors plays a crucial role in the thermoelectric refrigerator, which is the basis for how the refrigerator cools and transfers heat out.

N-type materials are doped semiconductors where the majority carriers are electrons (negative charges). When current flows through the Peltier module, electrons in the N-type material carry heat energy from one side of the module to the other. At the cold junction (where heat is absorbed), electrons in the N-type material absorb energy (heat) as they move toward the hot junction. At the hot junction (where heat is released), the electrons lose this energy, effectively transferring heat from one side to the other.

P-type material is positive charge carriers (holes) semiconductors, "holes" are the majority carriers. These are locations where an electron is missing in the atomic structure, and they move in the direction of conventional current. When current flows through the Peltier module, holes in the P-type material absorb heat at the cold junction (where the module touches the object being cooled).As they move toward the hot side (under electric field), they release heat at the hot junction (usually connected to a heat sink).The P-type material in a Peltier unit helps transfer heat from the cold side to the hot side by moving positive charge carriers (holes) that carry thermal energy. This is part of the thermoelectric process that allows the module to act as a heat pump when an electric current is applied.

The buzzer unit 122, makes use of the emitter and collector sensor to continuously monitor the battery level of the thermoelectric refrigerator during preservation and distribution of vaccines in the field.

The peltier cooling unit 123 makes use of a miniature low DC voltage cooling fan which acts as a heat exchanger to manage heat transfer efficiently by dissipating heat from the hot side of the thermoelectric refrigerator to prevent over heating of the hot side of the of the thermoelectric refrigerator, this is achieved by pulling heat away from the cold side and dissipate into the environment. This process increases peltier maximum cooling efficiency, reduces heat absorption by the thermoelectric refrigerator cooling surface and maintains the thermal gradient.

The LCD unit 117, displays real-time thermoelectric refrigerator parameters such as: internal temperature, humidity and battery level of the thermoelectric refrigerator processed by the microcontroller into observable format for on-site users.

Wi-Fi module unit 119 serves as the transmission link using Universal Asynchronous Receiver Transmitter (UART) to log in processed thermoelectric refrigerator parameters such as: internal temperature, humidity and battery level by the microcontroller to a web page for off-site observation of the data from the devices remotely.

Hardware design

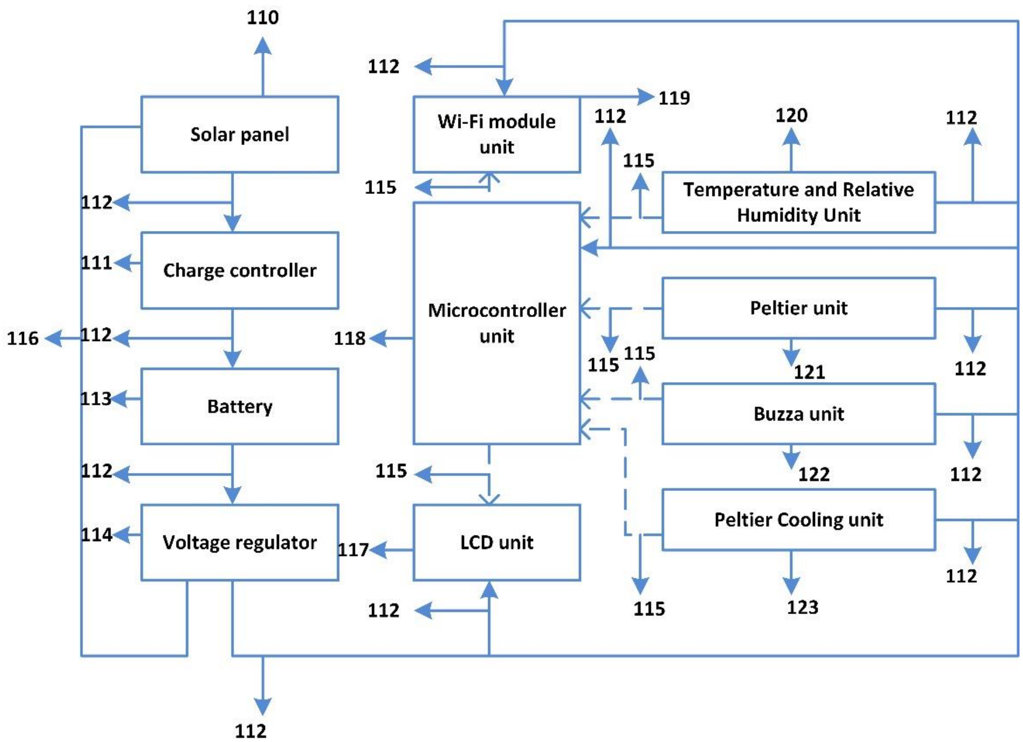

Fig 1: Block diagram of the device

Circuit diagram of the device

Below is the overall circuit diagram showing the interconnections between components that will be utilised to physically implement the thermoelectric refrigerator:

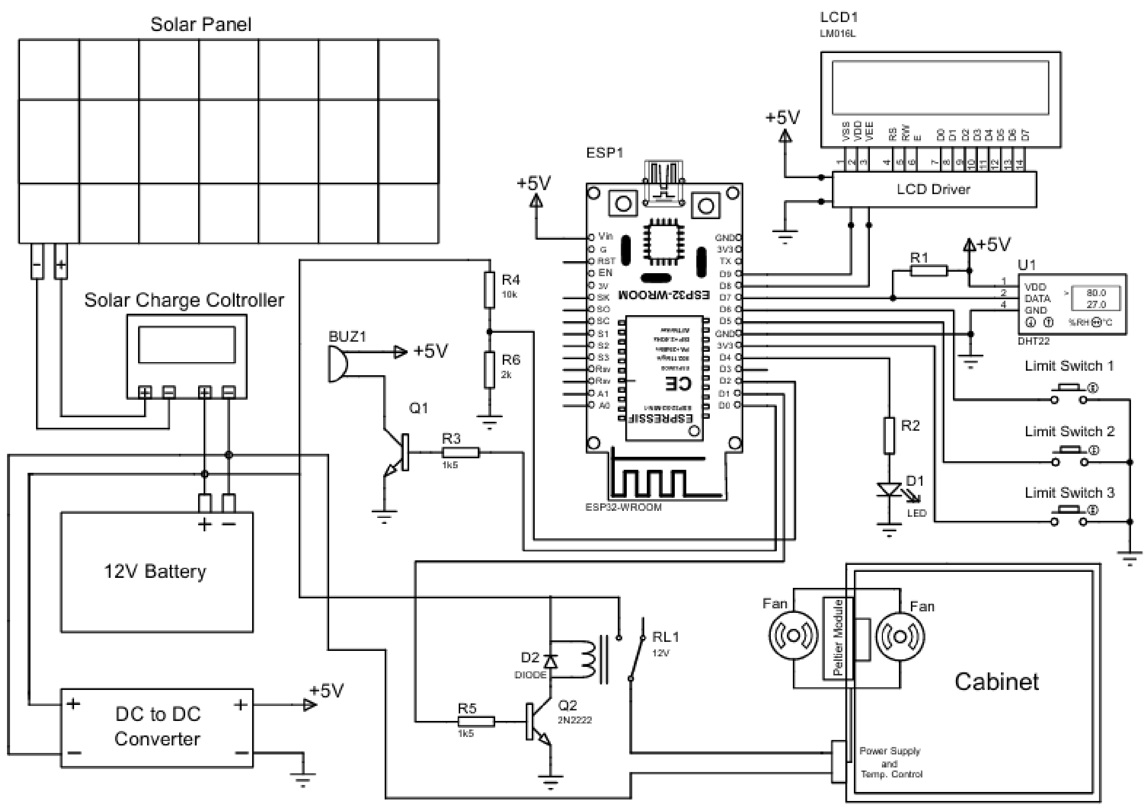

Fig 2: overall circuit diagram showing the interconnections between components

Development of the embodiment frame locally

For the development of the embodiment frame the following materials will be considered:

1. Resin
2. Accelerator
3. Catalyst
4. Fiber mat
5. Calcium dust
6. High density wood
7. Sand paper of different surfaces
8. Lathe machine
9. Solid work soft ware
10. Drill bit machine and drill bits
11. Plaster of Paris Solid Work software

This section depicts prototype thermoelectric refrigerator 3D solid work model showing front view, side view, back view and top view of plastic composite embodiment frame of the weather station respectively:

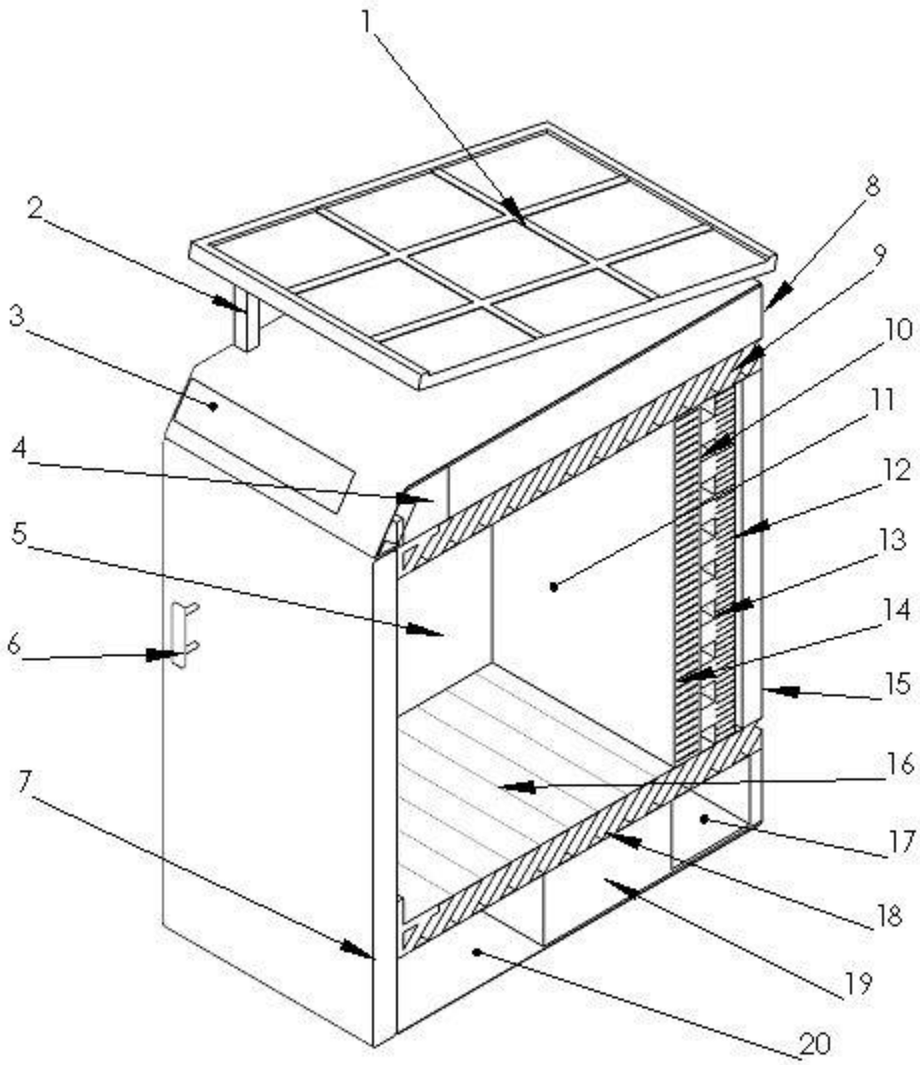

Fig 3: back transparent isometric view of the thermoelectric refrigerator

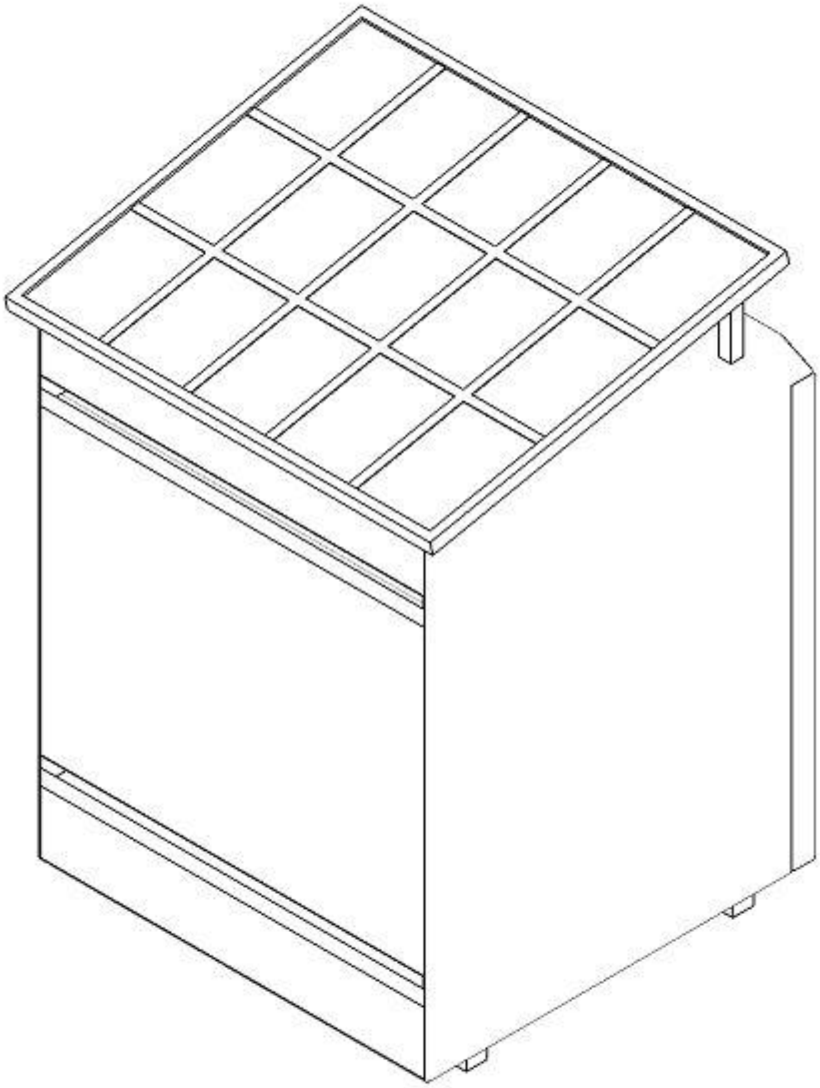

Fig4: back isometric view of the thermoelectric refrigerator

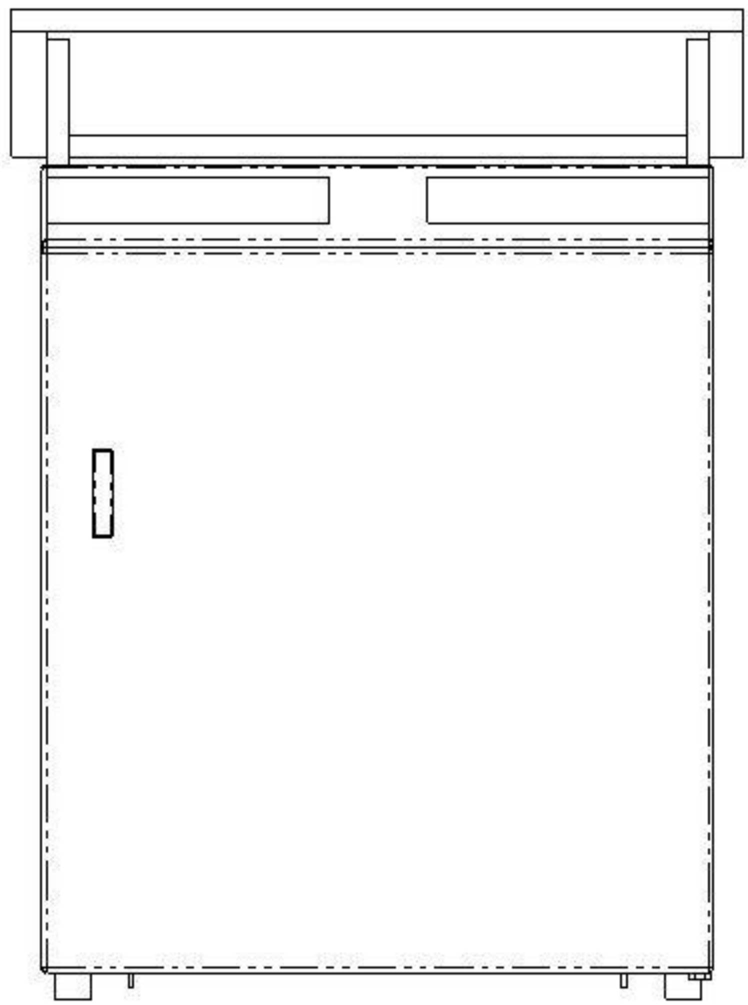

Fig 5: front view of the thermoelectric refrigerator

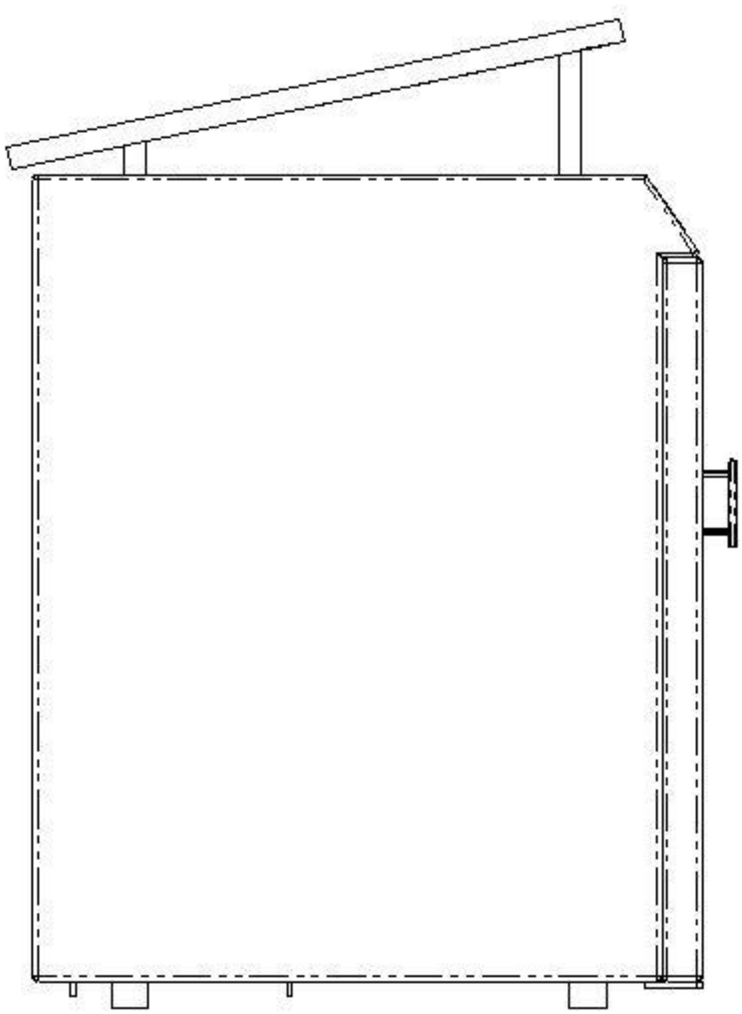

Fig 6: side view of the device

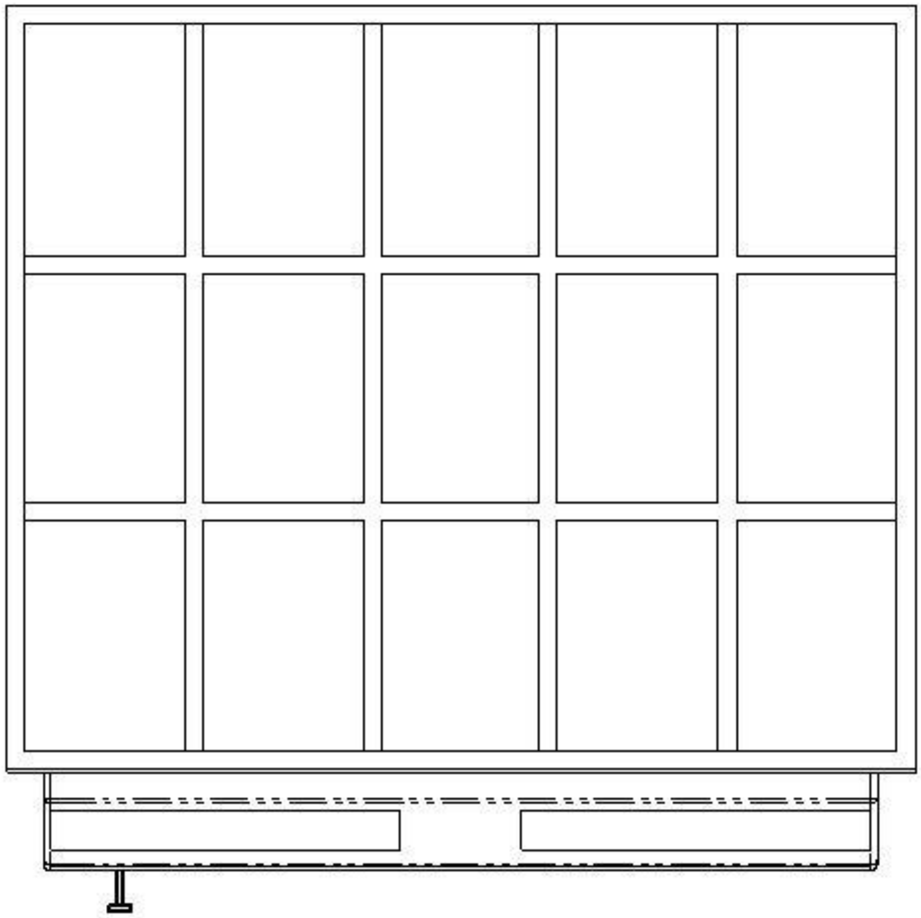

Fig 7: top view of the thermoelectric refrigerator powered by solar photovoltaic module and incorporating IoT

Fig 3 depicts back transparent isometric view of the thermoelectric refrigerator powered by solar photovoltaic module and incorporating IoT with labels numbered 1 to 20 with each label connoting a particular component.

The solar module which provides the needed electrical power to run the thermoelectric refrigerator through the conversion of solar energy into electrical energy is designated 1.

The bracket upon which the solar module titled on an angel of inclination is designated as 2

The LCD displaying different parameters of the thermoelectric refrigerator when deployed to the field for the purpose vaccine preservation and distribution is designated as 3.

The locally made reinforced composite plastic frame where the charge controller and voltage regulator is housed is designated as 4

The inner back locally made reinforced composite plastic frame cooling surface is designated as 5

The door handle of the thermoelectric refrigerator is designated as 6

The door of the thermoelectric refrigerator is designated as 7

The top reinforced composite plastic frame housing the circuitry components and sensors of the thermoelectric refrigerator is designated as 8

The top insulation layer inside the thermoelectric refrigerator which prevents heat gain into the cooling cabinet when the refrigerator is in operation is designated as 9.

The N-type semiconductor solid state component which makes up a major component of the peltier module unit is designated as 10

The inner side locally made reinforced composite plastic frame cooling surface is designated as 11

The hot side of the peltier module unit in the thermoelectric refrigerator is designated as 12

The P-type semiconductor solid state component which makes up a major component of the peltier module unit is designated as 13

The cold side of the peltier module unit in the thermoelectric refrigerator is designated as14

The exchanger chamber of thermoelectric refrigerator powered by solar module and incorporating IoT designated as 15

The inner floor locally made reinforced composite plastic frame cooling surface is designated as 16

The locally made reinforced composite plastic frame where the chamber for low DC voltage fan which maintains steady heat extraction from inside cabinet of the thermoelectric refrigerator is designated as 17

The bottom insulation layer inside the thermoelectric refrigerator which prevents heat gain into the cooling cabinet when the refrigerator is in operation is designated as 18

The locally made reinforced composite plastic frame where the battery is housed is designated as 19

The locally made reinforced composite plastic frame where the chamber for low DC voltage fan which maintains steady cooling effect to the inside cabinet of the thermoelectric refrigerator is designated as 20.

Expected Results from the Prototype Thermoelectric Refrigerator

1. real-time display of battery level, temperature and humidity level of the refrigerator when deployed in the field in digital numerical values for the health workers observation and monitoring on the LCD
2. off-site real-time visuals of the refrigerator's temperature, humidity and battery level in the form of digital numeric values and a continuous straight line graph that as shown on the LCD once every minute with the help of a Wi-Fi module. Additionally, these data will be automatically stored in an Excel file format on a cloud database.
3. The refrigerator will operate seamless on a low DC voltage independent of grid electricity and not susceptible to electrical shocks when moving vaccine for preservation and distribution in the field.
4. Solar module, charge controller and battery bank will achieve uninterrupted stable low DC power source during days of autonomy.
5. Thermoelectric refrigerator will have light weight due to Solid state miniature component such as Peltier refrigerant module and heat sink for vaccine preservation and distribution in the field.

Implementation plans

Having gotten the patent certificate at the concept and design stage it will be important to develop prototype and deployed to different regions of Nigeria. This will also give an opportunity for clear production line sequence of the thermoelectric refrigerator and modification of some design parameter after through performance evaluation and validation.

Implementation Plan

Project timeline (12 months)

Phase	Duration	Activities
Phase 1	3 Weeks	Literature review, patent search audit, system design, component procurement and assembly
Phase 2	3 Weeks	3D modelling, simulation and software development
Phase 3	4 Weeks	Careful soldering of electronic components and sensors on the PCB. Connecting the solar power system to interface with the entire circuitry
Phase 4	Months	Field testing of the thermoelectric refrigerator thorough performance evaluation

Phase 5	3 Weeks	Analysis of acquired thermoelectric refrigerator parameters by
Phase 6	3 Weeks	Validation of the thermoelectric refrigerator data

Estimated Cost of Thermoelectric Refrigerator Powered By Photovoltaic Module and Incorporating IoT

Below is a breakdown of the bill of quantity proposed for the prototype thermoelectric refrigerator production, the sum of Nine Million Seventy one and two hundred naira (**₦9, 071,200**) for the production of four thermoelectric refrigerators powered by photovoltaic module and incorporating IoT

S/N	Components	Quantity	Unit cost	Total cost
1	Pelter module	10	5680	56,800
2	Heat sink fan	1	60,000	60,000
3	Production of cold chamber mold	1	20,000	20,000
4	Production of 1 piece of the cold chamber	1	80,000	80,000
5	Temperature sensor	3	15,000	45,000
6	Relative humidity sensor	3	6,000	18,000
7	Charge controller	2	40,000	80,000
8	Deep cycle battery	1	250,000	250,000
9	Converter (DC-DC)	1	60,000	60,000
10	Microcontroller	3	14,000	42,000
11	Photovoltaic module	1	150,000	150,000
12	Display unit	3	7,000	21,000
13	Wireless communication link	2	18,000	36,000
14	Things platform	Free	Nil	Nil
15	Cables, connectors, fuse, wires	10 lots	6,000	6,000
16	Mounting bracelet	1	19,000	19,000
17	Double sided coated PCB	2	40,000	80,000
18	Metal structure	1 lot	14,000	14,000

19	Stainless steel material	1 lot	140,000	140,000
20	Cost of developing the machine language	-	280,000	280,000
21	Cost of embodiment development	1 lot	190,000	190,000
22	Miscellaneous	Nil	195,000	620,000
Total				**2,267,800**

For four thermoelectric refrigerators powered by photovoltaic module and incorporating IoT: **₦2, 267,800 × 4 = ₦9, 071,200**

Staffing and roles required

Principal Investigator **Engr. Sayeed M. Shuaibu:** B.Engr, M.Engr and P.hD in control and instrumentation engineering with specialization on Photovoltaic Module

Enyi E. Stephen : Bsc(Geology and Mining),MSc(Environmental Geology)

Ughanze Ifeanyi James: BTech in Physics Electronics. MTech in applied Atmospheric Physics with focus on Lower Atmosphere Instrumentation, P.hD in applied Atmospheric Physics with focus on renewable energy hybridisation and optimization.

Engr.UGWU CHINEDU LAWRENCE: B.Engr,: M.Engr and P.hD in Metallurgical and Materials Engineering Specialise in Foundry Metallurgy

Engr. Ahmed Mohammed Saba: B.Engr Computer Engineering, M.Engr in Control Engineering,P.hD in control and instrumentation engineering with specialization on renewable energy optimization and control

Maichibi Abraham : NCE/ first Degree in progress Electrical installation and Maintenance work

Abonyi Afamefuna Kenneth : B.Engr: Electrical Engineering Area of Specialization: Electrical Machines

Enoch Amadu : National diploma (ND) Electrical/Electronics specialize in house wiring and soldering

Evaluation

Performance Metrics: Data accuracy, uptime, transmission reliability, user satisfaction.

Data Review: Weekly system diagnostics, monthly analytical reports.

Conclusion

At the end, the outcome will be a thermoelectric refrigerator which utilises a microcontroller as its central processing unit which retrieves analogue and digital signals from the thermoelectric refrigerator peltier components, internal temperature sensor, humidity sensor, battery level sensor through appropriate pin connection with the device. The retrieved analogue and digital signals by the microcontroller will be processed into useful observable format and displayed on the LCD connected to the output pins of the microcontroller for on-site users of the thermoelectric refrigerator.

The LCD displays real-time thermoelectric refrigerator internal temperature, humidity and battery level.

For off-site visuals of the thermoelectric refrigerator parameters, Wi-Fi module will be interfaced in design with the pins of the microcontroller to act as a transmission link which will upload data to the Web page and dedicated server.

Real-time thermoelectric refrigerator parameters will be visualised on the Web page in digital numeric values and on a continuous straight line graph remotely, also the visualised thermoelectric refrigerator parameters will be archived on the dedicated server in an excel file format for future use.

Portability of the thermoelectric refrigerator powered by solar photovoltaic and incorporating IoT will be achieved by connecting solid state miniature cost effective components and sensors to the input pins of the microcontroller and also utilising locally available components materials.