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Design and Fabrication of Solar Powered Mobile Cold Room

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ABSTRACT

The Design and Fabrication of Solar Powered Mobile Cold Room is a refrigeration system that uses solar energy. It was embarked upon as a result of the epileptic power supply to the rural areas in the country and the absence of a grid supply to some locations where needed. The mobile cold comprises of the following components, the D.C compressor (Danfoss BD92K), charge controller (40A, 12V), solar battery (12V, 200AH), solar panel (12V, 600watt) and a 500litres compartment. The power is not supplied either from the national grid nor the generator system, but from the solar panel. The solar mobile cold room comprises of the solar panel that collects the solar energy. The solar panels convert the solar energy into electrical energy and stored it in the battery. During the normal running of the cold room, the power is supplied directly by the solar panel, but when the output power of solar panels is less, the additional power is supplied by the battery. The battery is recharged when excess amount of power is produced by the solar panels. The output supply of the batteries and the solar panel is DC with voltage of about 12V. A microcontroller was used to display the inner temperature of the freezer and also to protect the compressor by switching it off when the door is opened for a period of 60seconds. The charge controller is connected to the battery and solar panel to regulate the voltage from the solar panel for the charging of the battery, the supply from the battery is used in running the D.C compressor of the cold room in the absence of sunlight or when the sun intensity is low. The system is capable of running for 18 hours without the presence of sunlight when the battery is fully charged; it also has a high storage capacity of 500litres and longer operation time as compared to previous solar refrigerators.

KEYWORDS: *Design, D.C compressor, solar PV, microcontroller, back up battery, charge Controller*

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EXECUTIVE SUMMARY

This fabrication was carried out to further enhanced the global knowledge of using renewable energy resources which in turn reduce drastically the challenges faced in preservations of perishable food items, drinks, post-harvest and beverages for long period before they are finally consumed by the end users. However, the cold room has been built on a tricycle (cart) and as well accommodated the batteries and every other accessory needed.

INTRODUCTION

In the present erratic and epileptic energy Scenario Experienced by Nigerians from utility companies, it became inevitable to shift towards the use of renewable energy resources to bridge the gap of availability of perishable food items, cold drinks and beverages in rural area.

This design and fabrication was aimed at bridging the gap of socio-economy factors and unstable supplies of perishable food items, drinks and beverages to the rural area bearing in mind that food and perishable items deteriorates at ambient temperature.

Refrigerators used in daily life are one of the indispensable tools. Uninterrupted power should be supplied to refrigerators in order to maintain cooling service. Photovoltaic (PV) systems provide an independent, reliable electrical power source at the point of use, making it particularly suited to remote locations. For this reason, nowadays, the use of PV solar energy in refrigeration has been increasing in rural regions (Mehmet, 2011).

Photovoltaic (PV) powered refrigerator or freezer has a cooling capacity lower than typical alternative current (ac) unit because of its smaller compressor. Using the energy efficiently in solar or other renewable energy powered systems is more crucial than others since the limited sources and high costs for the storage capacity (Ekren, 2011).

AIM AND OBJECTIVE

The aim of this work is to Design and Fabricate a Solar Powered Mobile Cold Room

The following are the objectives of this fabrication;
- To use Renewable Energy Source to eliminate the use of Fossil Fuel and Electricity to Power the cold room.

- To Bridge the gap of Non-availability of cold drinks in Rural Areas.
- To extend the shelve life of perishable food items and post-harvest in off grid areas.

METHODOLOGY

DESIGN AND FABRICATION

Solar panels are comprised of several individual solar cells. These solar cells function similarly to large semiconductors and utilize a large-area p-n junction diode. When the solar cells are exposed to sunlight, the p-n junction diodes convert the energy from sunlight into usable electrical energy. The energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their orbits and released, and electric fields in the solar cells pull these free electrons in a directional current, from which metal contacts in the solar cell can generate electricity. The more solar cells in a solar panel and the higher the quality of the solar cells, the more total electrical output the solar panel can produce.

Methodology

In designing and fabricating a micro-controller based solar mobile cold room, there are many guides involved in the design. This guide provides the information to correctly select the compressor, batteries, solar array, wiring, the blower (cooling fan), limiting resistors, metal sheet, aluminum sheet, and many others. The method adopted in this study is purely experimental. The device was designed using mathematical analysis and was converted into experiment by following the design results obtained in procuring the needed materials for the design.

Principle Applied

There are many procedures used in this project work and they are:

1. Freezer volume (constructed i.e 500ltrs)
2. Load requirement
   - Compressor size
   - Size of cooling fan (chosen)
3. Sizing the main control switch
4. Determination of backup size
5. Determination of PV size
6. Selection of charge controller

In designing solar powered mobile cold room, the following steps were taken:

1. Selection of freezer volume:

Here a 500 litres volume of cold room was constructed

2. Load requirement:

The total load including the compressor, the fan and the microcontroller power will be calculated.

Compressor size, Size of cooling fan and microcontroller power

The compressor size was selected from Danfoss compressor data sheet (compressors.danfoss.com). From the data sheet, the compressor suitable for the 300litres volume is BD92K which has the total consumption of about 100W. Now let us denote the compressor power as P_C . The fan power can equally be denoted as P_F, so that the total microcontroller power will be denoted as P_{MCP}. With this, we can say that the total power can be expressed as;

$$P_T = P_C + P_F + P_{MCP} \quad (1)$$

3. Sizing of the main control switch and the Power consumption demand

The switch is best chosen when equation 1 has been implemented or by calculating the power consumption demand, using the relation;

Total load = total load required x period of usage (Wh/day) (LEONICS, 2013) (2)

So that, the total PV energy needed = total load x 1.3 (Wh/day) (3)

4. Determination of backup size

Batteries store direct current electrical energy for later use (Washington State University Extension, 2009). The stored energy are later used at night in the absence of sunlight.

The formula below was used to calculate the backup size

$$Batter\ sise = \frac{(\text{Total Watt} - \text{hours per day used by appliances x Days of autonomy})}{(\text{0.8 x nominal battery voltage})} \text{ (LEONICS, 2013)} \quad (4)$$

Note that; days of autonomy is the number of days that you need the system to operate when there is no power produced by PV panels to get the required Ampere-hour capacity of deep-cycle battery. Similarly, 0.8 is for the depth of the battery discharge (compressors.danfoss.com).

5. Determination of PV size

A photovoltaic system is an array of components designed to supply usable electric power for a variety of purposes. When light shines on the cell it creates an electric field across the layers. The stronger the sunshine, the more electricity is produced (Al Qdah, 2015). This is used to charge the battery.

Stated in equation 5, is formula used to calculate the Total Wp of PV panel capacity;

Total Wp of PV panel capacity = Total PV energy needed / 3.43 (Wp) (5)

So that;

Number of PV panel needed = Total Wp of PV panel capacity/selected rating (measured in modules) (LEONICS, 2013) (6)

Where: W_P = watt peak of the panel

6. Selection of charge controller

The Solar Charge Controller or solar charge regulator is basically a voltage and/or current regulator to keep batteries from overcharging (Akinola, 2010). It basically regulates the output voltage and output current coming from the solar panels before going directly to the battery assembly. The solar charge controller regulates this 21 volts output of the panel down to what the battery needs at the time, also as per the requirement of the mobile cold room compressor at that period of time. This voltage varies from about 10.5 volt to 14.6 volt, depending on the state of charge of the battery and the surrounding temperature at that given point of time. Secondarily, it also provides protection against Overvoltage surges which would enhance the project controllability. It also prevents completely draining (deep discharging) by discharging only to 70-80% of its total capacity, thus enhancing the operating life of the batteries and providing a good pay back option (Akinola, 2010).

The size of the charge controller used in this project was calculated using the formula

Solar controller rating = No of strings x Isc of the panel x 1.3 (7)

Where: Isc = short circuit current of PV array

Design Flow Chart

This section shows the sequence of operation of the flow chat in figure 1

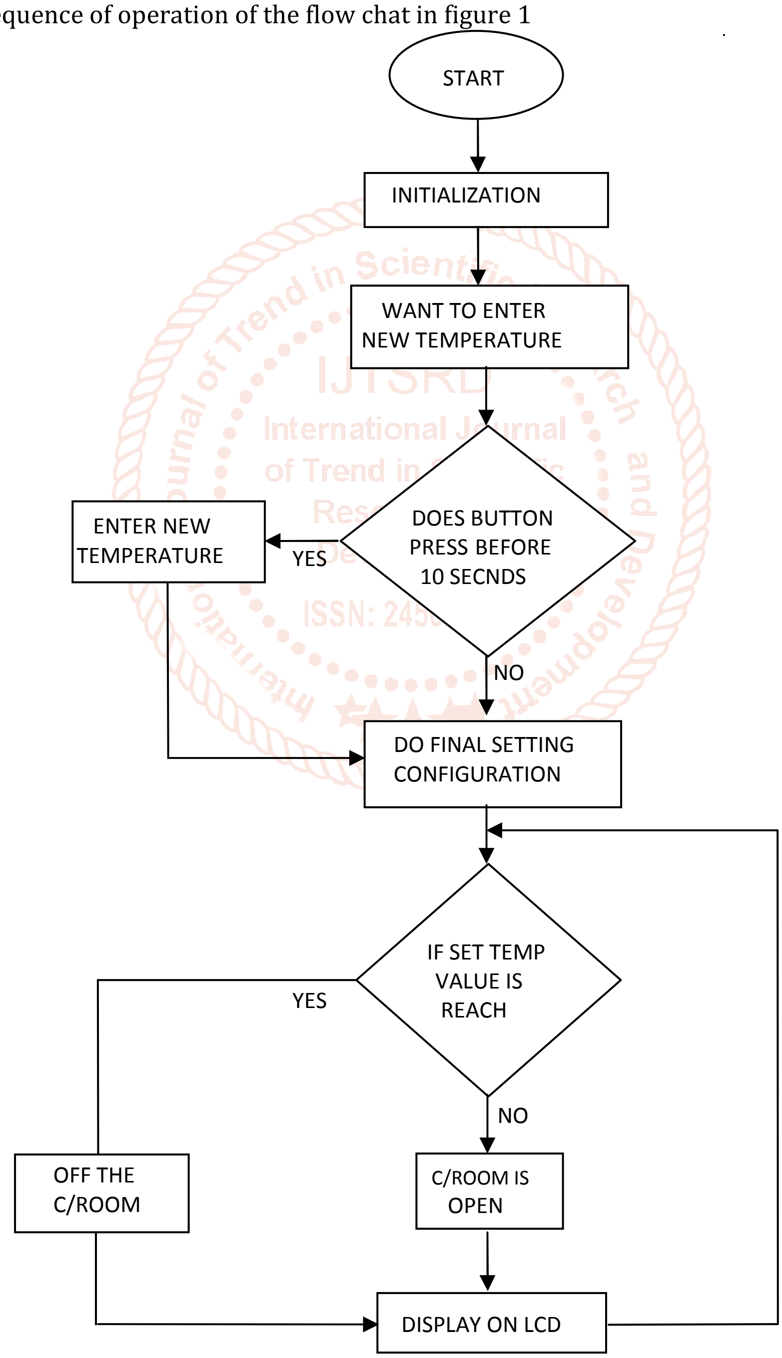

Figure 1: Design flow chart

Block Diagram.

The micro controller based solar powered freezer consist of eight stages and these stages are shown in figure 2

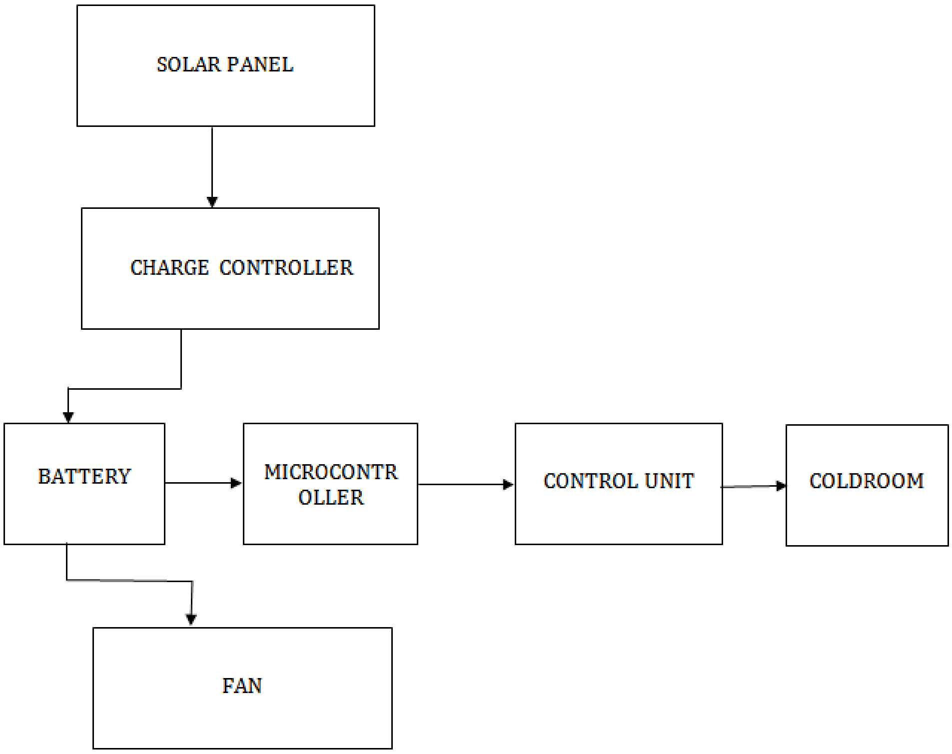

Figure 2: Block Diagram of the Solar Powered Cold Room

Procedure

The design procedures were broken down into the following steps:

- Selection of Compressor
- Metal sheet
- Aluminum sheet
- Determination of total load
- Duration of Operation (Battery Selection)
- Selection of Panel
- Programming of the micro controller

The above listed parameters were used to determine the efficiency of refrigerator required and consequently the amount of energy needed to power the system.

DESIGN

The adopted design principle for this project is that of systematic approach of the design; it entails the selection of appropriate components workable circuit biasing, selection of components to be used based on their operational characteristics and the utilization of the right materials' for the construction and perfect finishing.

Schematic Diagram of the work

Figure 3 shows the schematic diagram of the project which entails the layout of each component.

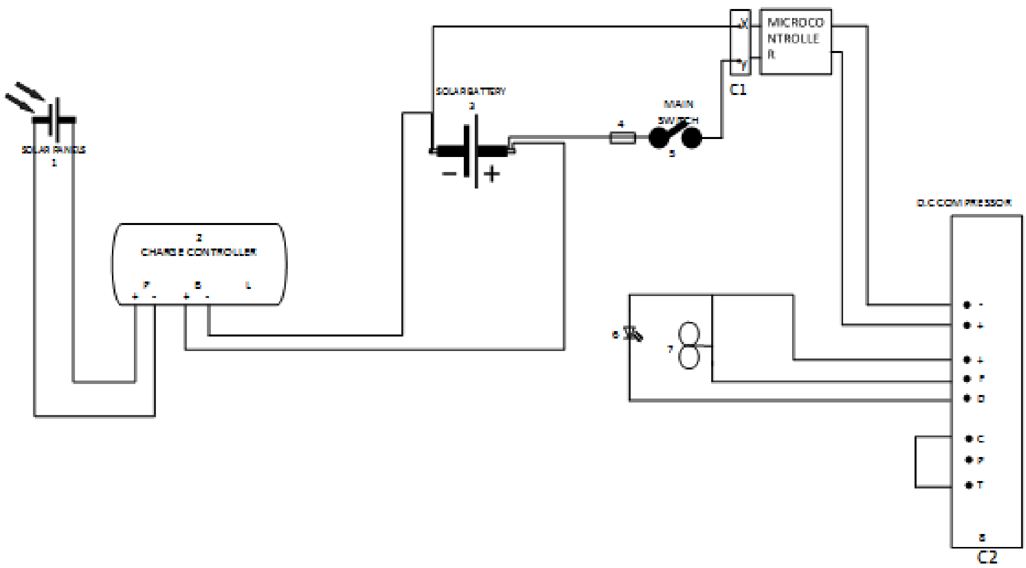

Figure 3: Schematic Diagram of the Design and Fabrication of Microcontroller Based Solar Powered Cold Room

Listed (figure. 3) are the components from the schematic diagram as used in this work.
1. Solar Panel (12V/600W)
2. Charge controller(12V/40A)
3. Solar Battery(12V/200AH)
4. Fuse
5. Main switch
6. Light emitting diode (LED)
7. 12VDC fan
8. DC Compressor (BD92K)

Determination of Project Values Using Schematic Diagram

1. Selection of direct current compressor

Table .1 Direct Current compressors with their input and output power (compressors.danfoss.com).

Model	BD36K	BD43K	BD52K	BD72K	BD92K	BD120K
Refrigerant	R600a	R600a	R600a	R600a	R600a	R600a
Displacement	2.5 cm³	3.6 cm³	4.3 cm³	5.2 cm³	6.6 cm³	9.1 cm³
Application	MBP/LBP	MBP/LBP	MBP/LBP	MBP/LBP	MBP/LBP	MBP/LBP
Voltage	DC12V~42V	DC12V~42V	DC12V~42V	DC12V~42V	DC12V~42V	DC24V~42V
Rotation RPM	2500~3500	2500~3500	2500~3500	2500~3500	2500~3500	2500~3500
Cooling Capacity	30~70W	40~90W	60~120W	80~180W	100~200W	120W~250W
Input Power	40W	55W	65W	80W	100W	120W
Current	3.3A (12V)	4.5A (12V)	5.5A (12V)	3.8A (24V)	4.2A (24V)	5A (24V)
Oil Charge	150 ml	180 ml	185 ml	185 ml	195 ml	250 ml
Cooling Type	Static cooling	Static cooling	Static cooling	Static cooling	Fan Cooling	Fan Cooling
N.W. (with control unit)	5 kg	5.5 kg	6 kg	6.5 kg	7.5 kg	8.5 kg

From table 1, the power of the selected compressor is found to be 100W, as seen in the shaded portion.
P=100W

2. Load requirement

In calculating the total load in this project work, equation 1 was adopted.
$P_T = P_C + P_F + P_{MCP}$ (eaquation1)
Recall that Pc = 100W
$P_F = 4.8W$
In that case, $P_T = 100 + 4.8 + 6 = 110.8W$
Or by using equation 2;
Total load = total load required x period of usage (Wh/day) (equation 2)
110.8W x 12 = 1329.6Wh/day
So that, the total PV energy needed = total load x 1.3 (Wh/day) (equation 3)
1329.6Wh/day x 1.3 = 1728.48Wh/day

3. Sizing of the main control switch

Since the total load power has been calculated using equation 3.1 and the result obtained is found to be 110.8W, joules's law can be applied and that is, P = IV
P = 110.8, V =12, therefore $I_{switch} = 110.8/12 = 9.23A$.

In this project, the switch used was that of 15A, which is capable of handling the required load current.

4. Determination of backup size

Recall that equation 4 is suitable for the battery selection

$$Battery\ size = \frac{(\text{Total Watt} - \text{hours per day used by appliances x Days of autonomy})}{(0.85 \text{ x nominal battery voltage})}$$

$$Battery\ size = \frac{110.8\ x\ 18hrs\ x1}{0.8x12} \times = 208AH$$

The nearest available battery in the market is 200AH, therefore, a 2 x 100AH battery was used

5. Determination of PV size

Recall that equation 5 is appropriate for PV selection
Total Wp of PV panel capacity = Total PV energy needed / 3.43 (Wp) (equation 5)
But in equation 3, total PV energy needed = 1728.48Wh/day
Therefore, Total Wp of PV panel capacity = 1728.48Wh/3.43 = 503.93Wp,
Similarly, Number of PV panel needed will be calculated thus;
Number of PV panel needed = Total Wp of PV panel capacity/selected rating (equation 6)
= 503.93/150 = 3.359 modules
Actual requirement = 4 modules
Here, charging time is assumed to be 8hrs

$$Charging\ current = \frac{200}{8} = 25A$$

Therefore, a 4 X 150W/6.5A solar panel was used to charge the battery effectively for the chosen time.

6. Selection of charge controller

Recall that in selecting the charge controller rating, the number of strings and the panel short-circuit current must be known; as such equation 7 was used
Solar controller rating = No of strings x Isc of the panel x 1.3
= 4 x 6.5 x1.3 = 33.8A
Therefore, a 12/40A charge controller was selected for this project work.

Circuit Diagram

The circuit diagram for micro controller based solar based cold room system is shown in figure 4.

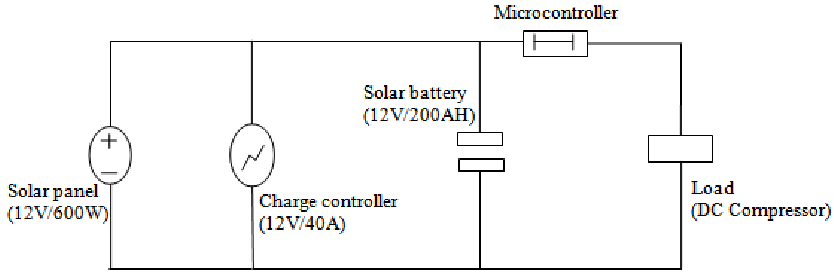

Figure 4: Project Circuit Diagram

CONSTRUCTION

The construction of the microcontroller based solar powered mobile cold room started by constructing a Cold room of 500liters (figure 5 – figure 13) from mild steel and aluminum with a total volume of 75 x 66.5 x 100 = 498750cm^3 = 500ltrs approximately (V = w x b x h cm^3). A 12V D.C compressor (BD92K,) the compressor was selected and was filled with R600a refrigerant. The 12V/200AH solar battery was used to power the cold room, the construction of each section were assembled to form a single unit. The selected Dc compressor was mounted and tightened properly using bolts and nuts. The discharge low suction line (pipe) of the compressor was welded to the inlet of the condenser pipe coils mounted at the back of the cold room (figure 3). The dryer (filter) was also welded to the outlet of the condenser pipe coils and a capillary tube welded to the dryer (filter). The capillary tube in turns welded to the inlet of the evaporator pipe, coils and outlet of the evaporator pipe coils welded back to the return low suction line of the D.C compressor, and finally the compressor was filled with R600a refrigerant through the charging pipe and sealed. After all these the cold room was put to a test to know all the parts were properly fixed and recorded huge success.

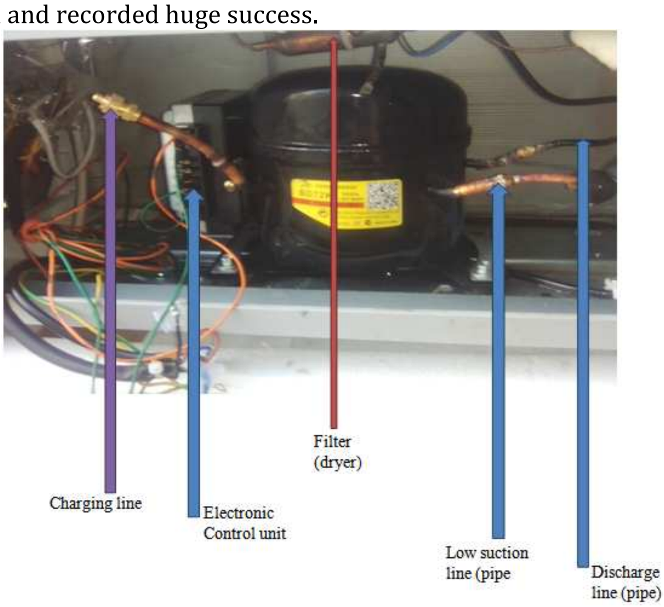

Figure 5: Constructional view

RESULTS

At the end of the fabrication, a functional mobile Solar Cold Room having the wall capacity of 500 litres with about 18hours of cooling when fully loaded was fabricated.

Table 2.Bill of Engineering Measurement and Evaluation

S/N	DESCRIPTION OF ITEMS	QAUANTITY	UNIT PRICE (₦)	TOTAL PRICE (₦)
1	TRICYCLE	1	550,000	550,000
2	12V/150W Solar Panels	4	45,000	180,000
3	12V/24V, 100W DC Compressor	1	160,000	160,000
4	Aluminum sheet	4ft x 8ft (16mm)	4375/mm	70,000
5	Mild steel	4ft x 8ft (16mm)	3750/mm	60,000
6	Condenser	1	20,000	20,000
7	Evaporator	1	21,000	21,000
8	12V/100AH Battery	2	50,000	100,000
9	12V/40A Charge Controller	1	50,000	50,000
10	Thermostat	1	5,000	5,000
11	63A Circuit Breaker	1	10,000	10,000
12	Capillary Tube	10meter 1,000/m	10,000	10,000
13	Refrigerant (R600a)	4	2,500	10,000
14	Cable 4mm2 (solar cable)	8m	600/m	4,800
15	Cable Log	10	100	1,000
16	12V DC Fan	1	2,000	2,000
17	Painting (glossary)	12ltrs	1,700/ltr	20,400
18	Micro-Controller (system automation)	1	70,000	70,000
19	Bolt, Nuts, and Washers		10,000	10,000
20	Laden		40,000	40,000
21.	Labour Cost		100,000	100,000
	TOTAL			**1,494,200**

CONCLUSION

A conventional prototype DC Cold Room was designed, fabricated and mounted in the tricycle. This project bridged the gaps of non availability of cold drinks and eradication of perishable food spoilage as a result of non constant/inadequate power supply in rural areas.

PICTORIA VIEW OF THE VENDING CART

Figure 6: Fixing of the Evaporator after the first padding

Figure 7: Final padding after the Evaporator

Figure 8: Front view of the mobile Cold Room

Figure 9: View with internal fabrication completed

Figure 10: Mounting of the Condenser

Figure 11: Mounting of the microcontroller and the charge controller

Figure 12: View showing all components mounted

Figure 13: View showing solar powered mobile cold room under test

PROBLEMS JUSTIFICATION

The device can be used for storage of food items, drinks, beverages and vaccines.

Mobile Solar Cold Room is ideally suited for countries, places, and remote areas where electricity power is epileptic or not easily available. It promises to be of high demand by those whose businesses centered on perishable food items, beverages and drinks, and primary health centres.

It also bridges the gaps of non-availabilities of perishable food items, drinks, and beverages to rural areas.

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