# Development of Solar Powered Herbarium Cabinet from Locally Sourced Material for Sub-Saharan Africa

**Wadai J.[1], Musa T.[2] and Cosmas T.[3]**

*[1,3]Department of Mechanical Engineering, Federal Polytechnic Mubi, PMB 35, Mubi, Adamawa, Nigeria.*
*[2]Department of Biological Science Technology, Federal Polytechnic Mubi, PMB 35, Mubi,*

---***---

**Abstract:** *The paper address the challenges faced by the floristic and taxonomic sector in Nigeria by design and developing a solar powered herbarium cabinet. The principle of vapor compression refrigeration cycle is utilized in designing the cooling system. Heat loss in the herbarium cabinet was insignificant during operational analysis. The desired 'paste control' conditions of temperature up to -18°c, and 50% relative humidity was 94% achieved when the herbarium cabinet was cooled to -17°c, and 62% relative humidity after six hours cooling period at full capacity. Thus, the heritage of vascular plants, bryophytes, lichens, algae, and fungi would be redeemed from extinction when Institutions, Government at all levels and Private researchers embraces the use of the reliably affordable solar powered herbarium cabinet.*

***Keywords: solar power, herbarium cabinet, indigenous plants, locally sourced material***

## I. INTRODUCTION

The term "herbarium" refers to the collection of plant specimens that are pressed on sheet of paper, dead and dried, preserved, sequentially arranged and classified for future purpose and study (Bridson et'al, 1998; and Heberling et'al, 2017). The said specimen samples are stored in the form of a floristic and taxonomic data in a dry and controlled environment (Jacek, 2008). Some regional and institutional herbaria collections that are of world recognition today are well above 3000 (Gills, 1992).

Nigeria being a populous nation in African is endowed with large forest reserves, herbs and flowers whose existence amid the country' economic and security challenges is greatly threatened by deforestation. Today, it has been established that over 7895 identified plant species in Nigeria are faced with rapid threat of extinction due to poor monitoring and evaluation principles. Thus, the heritage of the said plant species threatened amid the economic and security challenges in Africa and Nigeria has led to nearly impossible forest tourism, visitation, excursion and academic research works (Nigerian Biodiversity report, 2010). These challenge in developing countries like Nigeria are glaring; due to poor research policies of the Government, Institutions and reluctant attitudes of individuals towards reclamation of the herbarium archives. This is nearly or completely leading a step to extinction of even the long preserved traditional medication enjoyed.

## II. OBJECTIVES

- To design and develop a safe, secured, pest controlled and economical viable solar powered herbarium cabinet with guaranteed temperature and humidity control for Nigeria and African region from locally available material.
- To encourage and re-emphasize the floristic and taxonomic data management as a tool for educational information amid extinction.
- To help in redeeming the heritage of the region's vascular plants, bryophytes, lichens, algae, and fungi from extinction.
- To provide solid basis for traditional medicine's 'heritage reclamation', research and control.

## III. DESIGN AND DEVELOPMENT

### Material Selection and Product Design Specification

Based on the availability of the locally sourced engineering materials, the herbarium cabinet is designed in conformity with the engineering specification.

Table 1: list of materials and design specifications

| S/No. | Description | Specification |
|---|---|---|
| 1 | Product Name | Solar powered herbarium cabinet |
| 2 | Standard machines | 2kw scroll hematic compressor, evaporator, condenser, expansion or |

| | | |
|---|---|---|
| | | throttle valve, thermostat, solar panel, inverter, and a voltage control unit |
| 3 | Targeted customers | Institutions, Ministries, and Private researchers |
| 4 | Materials for bodywork | Galvanized steel sheet, and aluminium sheet |
| 5 | Lagging material | Rice husk and binding agent (cassava starch) |
| 6 | Manufacture | Fabrication techniques |
| 7 | Safety | Avoid sharp edges and always use recommended safety wears and codes |
| 8 | Service life | 30 years |
| 9 | Operating temperature range | -18°C to 55°C |
| 10 | Relative humidity | 50% to 60% |

**Bodywork Design**

The bodywork design of the solar powered herbarium cabinet is in form of two-layer rectangular cabinet:

1. The outer bodywork fabricated from a galvanized sheet metal.
2. The inner bodywork fabricated from an aluminium sheet metal.

Both outer and inner bodywork are fabricated by welding, riveting and soldering processes; and are separated by a rice husk as lagging material.

**The Outer Body Work Design**

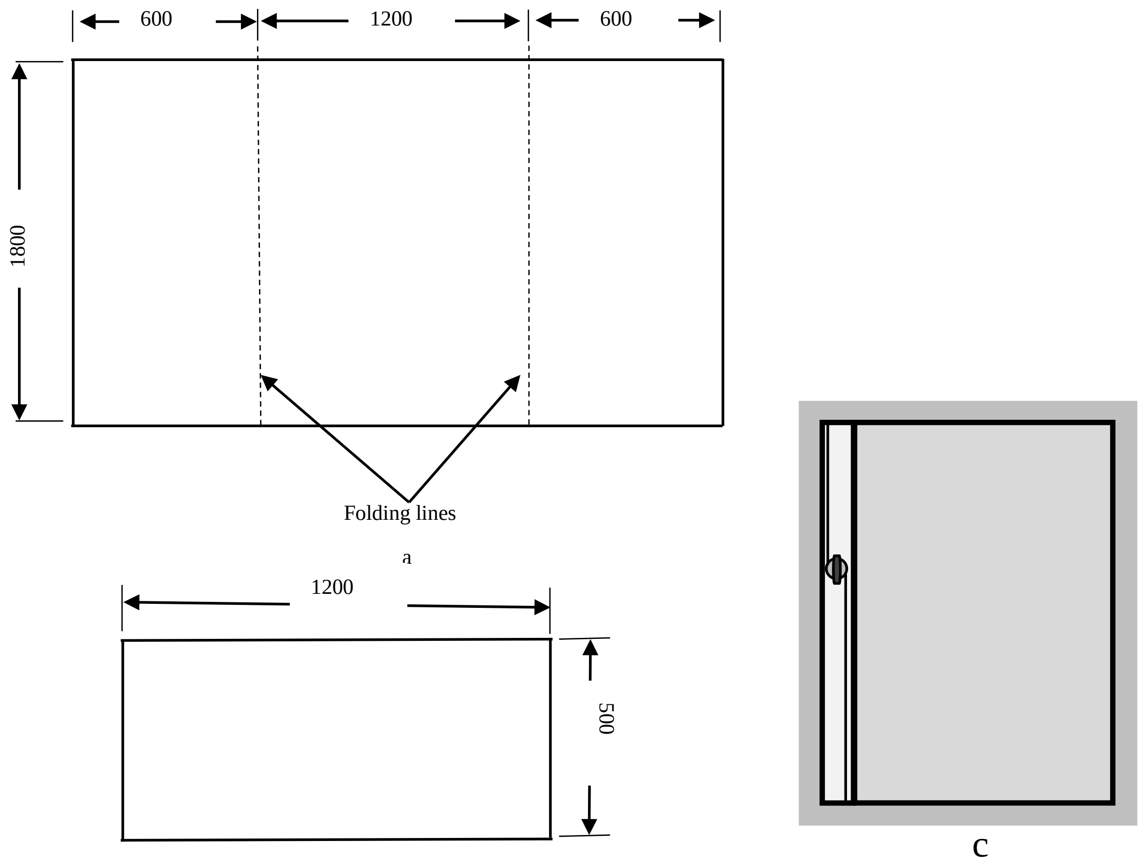



Fig (1). The outer bodywork fabricated from a galvanized sheet metal showing: (a) back and two sides folding lines; (b) Top and bottom plate and (c) Two front covers.

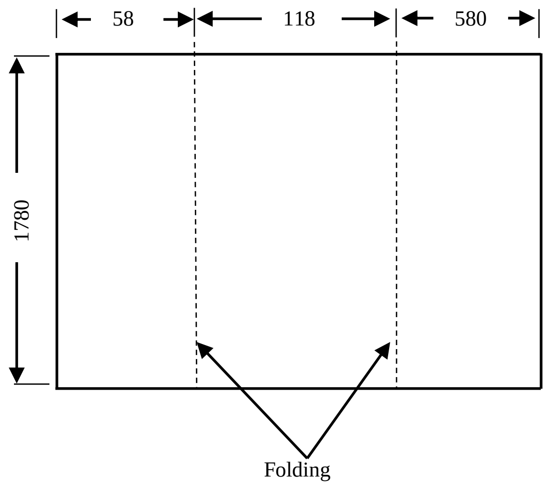
**Data for calculation for outer bodywork - Galvanized sheet metal**

- Length of the cabinet (l) = 1200mm = 1.2m
- Breadth of the cabinet (b) = 500mm = 0.5m
- Height of the cabinet (h) = 1800mm = 1.8m

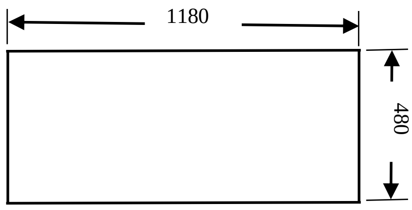
Given that the volume of the outer galvanized bodywork = $V_g$

$$\Rightarrow V_g = (l \times b \times h) = (1.2m \times 0.5m \times 1.8m) = 1.08m^3$$

**The Inner Body Work Design**




a




b

Fig (2). The inner bodywork fabricated from an aluminium sheet metal showing (a) Back and two side folding lines; (b) Top and bottom plate

**Data for calculation of inner bodywork - Aluminium sheet metal**

- Length of the cabinet (l) = 1180mm = 1.18m
- Breadth of the cabinet (b) = 480mm = 0.48m
- Height of the cabinet (h) = 1,780mm = 1.78m

Given that the volume of the inner aluminium bodywork = $V_a$

$$\Rightarrow V_a = (l \times b \times h) = (1.18m \times 0.48m \times 1.78m) = 1.008m^3$$

**The Lagging Material**

Rice husk being selected as the lagging material is considered in preference to other possible lagging materials due to its readily availability, cheaply sourced and ability to last for about 40years even at temperatures up to 80°C in the absence of moisture (Goncalves et'al, 2007). Cassava starch, due to its ability to bind and sustaining the rice husk without warping at 80°C made it most suitable binder selected (Doue et'al, 2014).

**The volume required for the lagging material ($V_{lag}$).**

The rice husk lagging material mixed with cassava starch as binder will occupy space between the outer and the inner bodyworks. This space is the differences between the outer bodywork made from a galvanized sheet metal and the inner bodywork made from aluminium sheet metal.

$$V_{lag} = (V_g - V_a) = (1.08m^3 - 1.008m^3) = 0.072m^3$$

**Temperature and Relative Humidity Control in The Herbarium Cabinet**

The herbarium cabinet is designed to operate based on the 'vapor compression refrigeration cycle' due to the energy efficiency of the principle. The herbarium cabinet is fitted with a 'low temperature programmable thermostat' that operates between -20°C and 60°C, to control the temperature and relative humidity of the system (Wathsala et'al, 2014).

The vapor compression refrigeration cycle is a process that are of four major stages.

***The compression process:*** The temperature of the refrigerant is raised at this stage by the compressor that does work on the system.

***The condensation process:*** The heat transfer process takes place in this zone, as the heat is taken away from the refrigerant by the flow of water in the condenser.

***The expansion/ throttling process:*** The temperature drops at this level at high velocity, low pressure; making the refrigerant leaving the throttle valve as a liquid-vapor mixture.

***Evaporation process***: The refrigerant at this stage evaporates and absorbs latent heat of vaporization at low temperature and pressure.

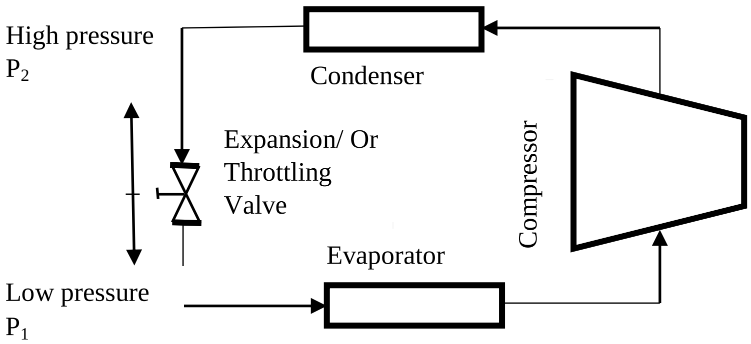



Fig. 3. Schematic representation of the vapor compression cycle of the solar powered Herbarium Cabinet

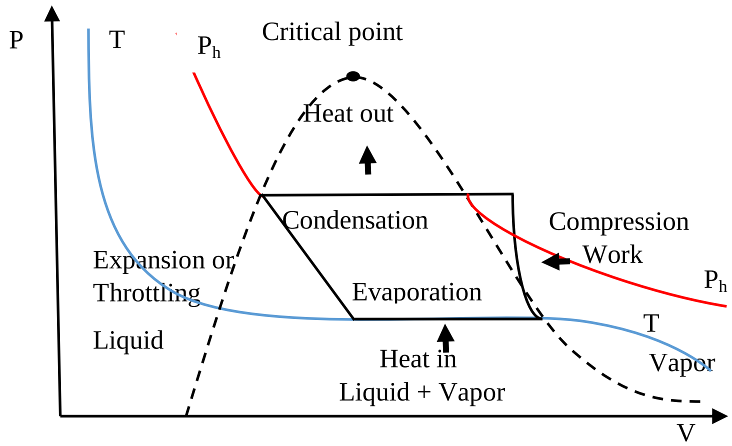



Fig. 4: Vapor compression Refrigeration cycle (Mahmoud et'al, 2015)

**Heat Transfer (Lost) Analysis in the Herbarium Cabinet**

The heat transfer in the herbarium cabinet is a combined conduction-convection process across the boundary layer of the composite wall of the cabinet as governed by the Fourier's law (Goncalves and Carlos, 2007).

The Fourier's law states that: "the rate of heat transfer across a boundary layer of cross-sectional material is directly proportional to the temperature difference'.

$$\Rightarrow \rho \, \alpha \, A\Delta T$$

$$\Rightarrow \rho = h \, A\Delta T$$

Where α=$h_c$, the combined conduction – convection coefficient.

A = Cross-sectional area of the composite wall

When the herbarium cabinet is tried to be cooled from 60°C to -20°C for one hour, free air convection coefficient $h_c$ = 23W/m³K.

Therefore, considering the schematic representation of the lagged – wall, and the heat loss (transfer) process as shown in Fig. (5) below

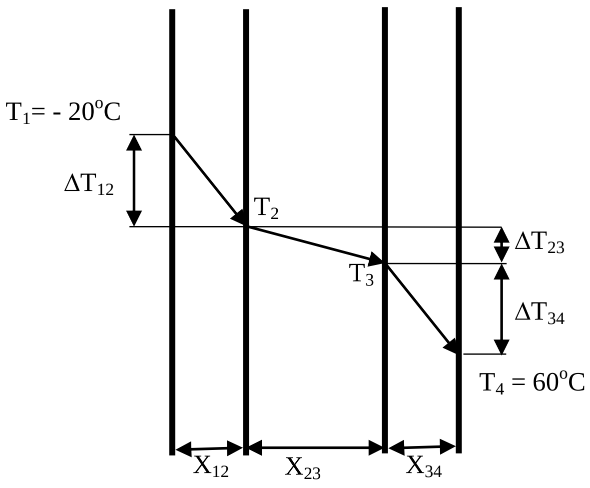



Fig. (5). lagged wall heat transfer process.

The Fourier's one dimensional steady state conduction through the composite wall of the solar powered herbarium cabinet now becomes.

$$\rho = -K_{12}\frac{T_2 - T_1}{X_{12}} = -K_{23}\frac{T_3 - T_2}{X_{23}} = -K_{34}\frac{T_4 - T_3}{X_{34}}$$

The overall heat transfer coefficient becomes

$$\left[\left(\frac{K_{12}}{X_{12}}\right) + \left(\frac{K_{23}}{X_{23}}\right) + \left(\frac{K_{34}}{X_{34}}\right)\right] = U$$

$$\therefore \rho = -U(T_4 - T_1)$$

**Heat transfer data**

- Aluminium steel thickness ($X_{12}$) = 1mm
- Thermal conductivity of Aluminium at 253°K = 204.32W/m³K
- The thickness of lagging wall – rice husk ($X_{23}$) = 10mm.
- Thermal conductivity of rice husk between - 20°c to 60°C ($K_{23}$) =0.085W/m³K
- Thickness of galvanized sheet metal ($X_{34}$) = 1.5mm
- Thermal conductivity of galvanized sheet metal 60°C ($K_{34}$) = 55.08W/m³K

## IV. THE SOLAR POWER SUPPLY UNIT

The photovoltaic (PV) conversion process is suitably adopted for the design of the power unit, due to its ability of direct conversion of the sun rays into electric energy through the use of the photocells (Akinbami, 2001). A 30kw, 320V, 45A and 50Hz solar plant is deemed fit for the generating of the require power output (Wadai et'al, 2018).

The schematic arrangement showing power supply designed to power the herbarium cabinet is presented in figure 5, on the appendix page.

## V. RESULTS

The cooling process test was conducted in four stages aiming at achieving the desired low temperature of -18$^{o}$C, relative humidity of 50% in the 'solar powered herbarium cabinet'. The temperature and relative humidity are measured at each interval of cooling period as summarized on the table below.

Table 2: cooling period test on the '***solar powered herbarium cabinet***'.

| S/No. | Cooling period | Initial temperature | New temperature obtained | Relative humidity |
|---|---|---|---|---|
| 1 | two hour | 29$^{o}$C (302) | -4$^{o}$C (269$^{o}$K) | 48% |
| 2 | Three hour | -4$^{o}$C (269$^{o}$K) | -9$^{o}$C (264$^{o}$K) | 53% |
| 3 | Four hours | -9$^{o}$C (264$^{o}$K) | -13$^{o}$C (260$^{o}$K) | 58% |
| 4 | Six hours | -13$^{o}$C (260$^{o}$K) | -17$^{o}$C ( 256$^{o}$K) | 62% |

**Solar Power Herbarium Cabinet Cost Estimate**

Solar powered herbarium cabinet cost estimate is done in the two categories as summarized on the table below.

| S/No. | Machine/ equipment | Power specification | Naira Cost (₦) |
|---|---|---|---|
| 1 | 24 compartment Herbarium cabinet | 2 Kw | 205,350:00 |
| 2 | Solar power system | 30 Kw | 2,410,430:00 |
| **Total cost** | | | **2,615,780:00** |
| **Cost of Imported Herbarium Cabinet** (BioQuip Products) | | | |
| **S/No.** | **Catalog No./ Color** | **Size** | **Dollar cost with Naira equivalent** |
| 1 | 3212/ Olive green or Grey enamel | 12 compartment | $1,370.41 = ₦664,648.85K |
| 2 | 3226 Olive green or Grey enamel | 26 compartment | $2,278.87 = ₦1,105,251.95k |

## VI. DISCUSSION

The solar powered herbarium cabinet designed and developed is a double cabin which consist of twenty (24) chest drawers that can contain five (5) herbarium folders well ventilated.

When the herbarium cabinet was fully loaded and tested. The test results that was carried out in four (4) stages indicate that a paste control lower temperature of -17$^{o}$C (256$^{o}$K) and relative humidity of 62% was achieved in six hours total cooling time.

The paste control lower temperature result obtained indicates coefficient of performance 94% of the -18$^{o}$C (255$^{o}$K) designed temperature. Though the relative humidity of 62% was greater than the designed relative humidity of 60% by 2%; it is still within the acceptable range (Staffan, 2006).

The cost analysis of solar powered herbarium cabinet as indicated on table 3 above though has a high initial cost due to the solar power station' cost, is much realistically affordable compared to the imported one using the conventional power supply. Thus, the solar powered herbarium cabinet renders more economic possibility to our region amid the poor economic tendencies that keep depreciating the value of Nigerian currency in the parallel market.

## VII. RECOMMENDATION

To ensure sustainability in preserving the heritage of African/ Nigerian floristic and taxonomic data.

i. There should be inclusive local technology utilization of the suitably affordable herbarium cabinet designed for developing world.
ii. Institutions, Governments at all levels, and Private research organizations should encourage more research work in this area or similar.
iii. The poor academic funding ethics of the government should be augmented by 'group student' projects' in similar research work.

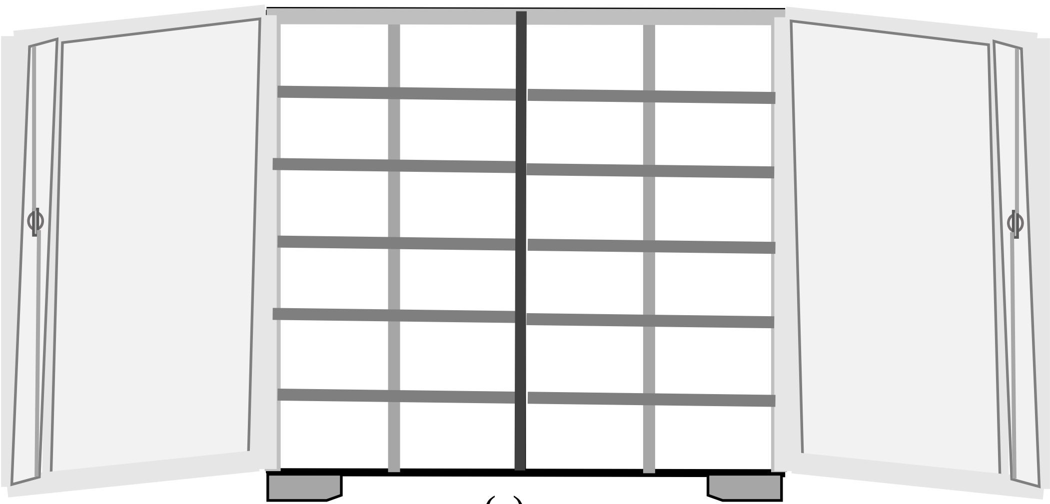
## VIII. CONCLUSION

This paper focuses on providing and obtaining a cheap, reliable and sustainable solar powered herbarium cabinet that is affordable to developing African countries and under-funded Institutions. This will as a matter of essential needs, mitigate the economic and insecurity challenges bedeviling Africa and Nigeria by enabling more job opportunities among youths even for collecting herbaria samples.

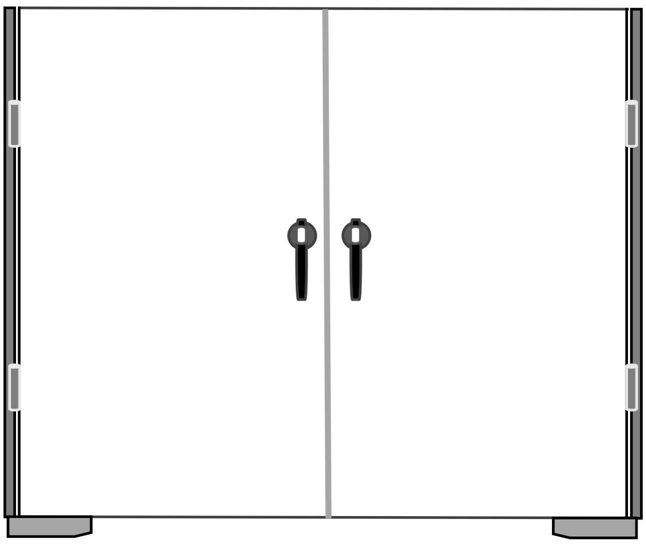
## IX. REFERENCES

1. Akinbami, J.F.K. (2001). Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospects and Policy Framework. Mitigation and Adaptation Strategies for Global Change, Kluwer Academic Publishers: Holland, The Netherlands, 6:155-181.
2. Becker. (2000) "Solar Thermal Power Plants." Prepared for the EUREC-Agency Drafted Version with Status.
3. Botany Equipment and Supply. "https:// Herbarium/ Steel Herbarium Cabinet-BioQuip products, inc.html.
4. Bridson, D. and L. Foreman (1998). The Herbarium Hand. "Royal Botanic Gardens, Kew, Great Britain". Third Edition.
5. Doue G. Gladys; Megnanous Rose-Monde; Bedikou E Michael and Niamke L. Sabastien (2014). Physicochemical Characterization of Starches from Seven Improved Cassava Varieties: Potentiality of Industrial Utilization. "Journal of Applied Biosciences 73, pp. 6002 – 6011.
6. FMEnv, (2010). Nigeria Fourth National Biodiversity Report, Federal Ministry of Environment, Abuja. Pp.42.
7. Gills, L. S. (1992). Taxonomy of Flowering Plants. Africana – FEP Publishers limited, Onitsha, Nigeria. Pp338.
8. J., Mason Herberling and Bonnie, L. Isaac (2017). Herbarium Specimens as Exaptation: New Uses for Old Collections. American Journal of Botany, Vol. 104.
9. Jacek Drobnik (2008). Modern Techniques of Herbarium Protection. "Environmental Challenges and Biological Assessment Iv, Scripra Facultatis Rerum Naturalium Universitatis Ostraviensis,186.
10. M.R.F., Goncalves and Carlos P. Bergmann (2007). Thermal Insulators Made with Rice Ashes: Production and Correlation Between Properties and Microstructure. "Journals of Construction and Building Materials, 21 (12); pp. 2059 – 2065.
11. Mahmoud, A. Alzoubi and Tie, Jun Zhang (2015). Characterization of Energy Efficiency Vapor Compression Cycle Prototype with Linear Compressor, "Energy Procedia 75, pp. 3253 – 3258".
12. Segun, R. Bello; T. A. Adegbulugbe and P. S. N, Onyekwere (2010). Comparative Study On Utilization of Charcoal, Sawdust, And Rice Husk in Heating Oven. Agricultural Engineering International: CIGR Journal, 12 (2), pp. 29 – 33. (https://www.cigrjournal.org).
13. Staffan, M.W. (2006). Linnaeus Herbarium Cabinet: A Piece of Furniture and Its Functions. "Endeavour, Vol. 30, 1ssue 2, pp. 60 – 64.
14. Wadai, J.; Cosmas T. and A.E. Zira (2018). Exploration of Solar Energy Utilization for Power Generation in Yola. "International Journal of Engineering and Science (IJES), Vol. 7, issue 10 Ver. Ii, pp. 07 – 14.
15. Wathsala, Perera; Carlos, F. Pfeiffer and Niels-Olav, Skeie (2014). Control of Temperature and Energy Consumption in Building: A Review. "International Journal of Energy and Environment (IJEE); Vol. 5, Issue 4, pp. 471 – 484.

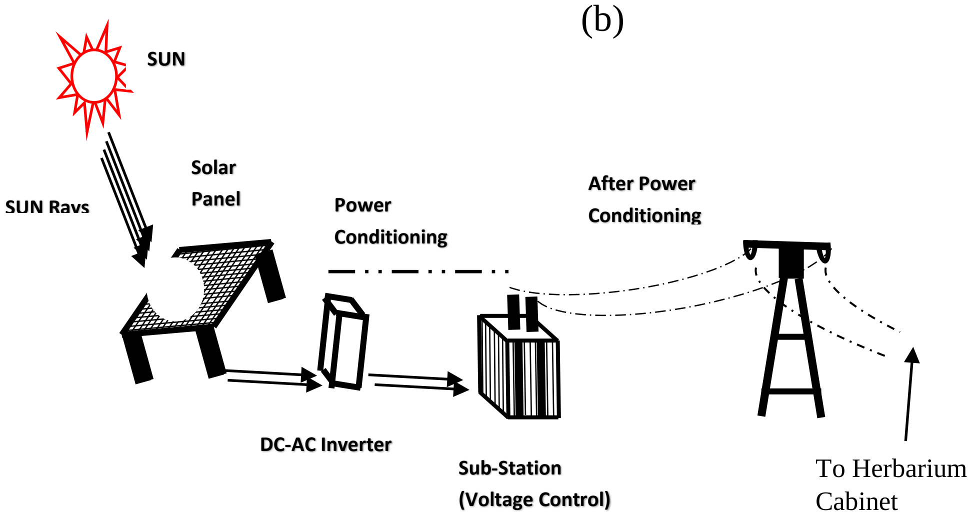
**APPENDIX**



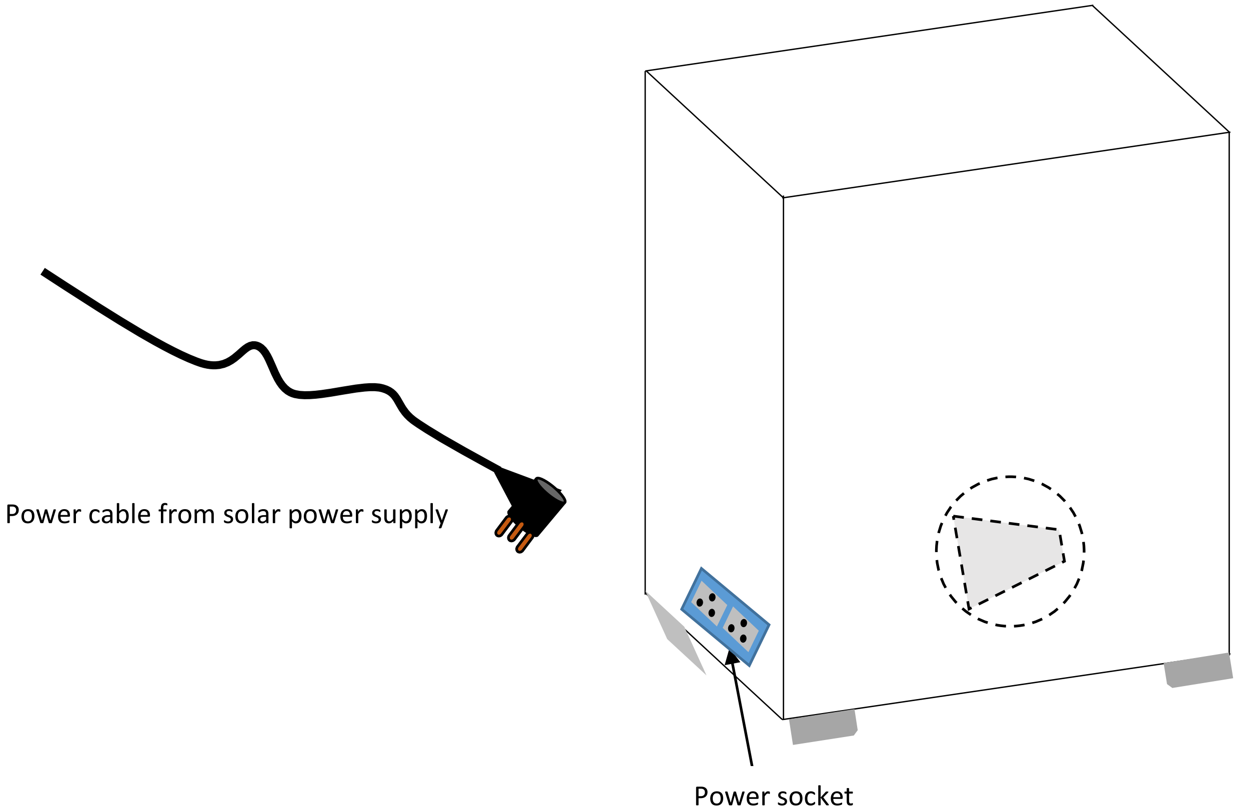
(a)



(b)




(c)




(d)

Fig. (3). The solar powered herbarium cabinet showing: (a) Front view in open position; (b) Front view in closed position; (c) The solar power schematics and (d) isometric view showing power supply/ connection.