IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

Design and Fabrication of Solar-Powered Refrigerator for Off-Grid and Rural Applications

Rohithkumar H. V.[1], Chandrashekara C. S[2]., Renukaraju H. J.[3], Tharun M. G.[4], Benebict Akash C.[5]
Department of Mechanical Engineering
Kalpataru Institute of Technology, Tiptur, Karnataka, India
(Affiliated to Visvesvaraya Technological University, Belagavi – 590014, Karnataka, India)
rohithmailbox@gmail.com[1] ,chandrashekharac892@gmail.com[2] ,renukaraju3666235@gmail.com[3]
,tharuntharu241@gmail.co[4] ,benedictakash87@gmail.com[5]

Abstract: *Refrigeration is fundamental for food preservation, dairy freshness, and the cold-chain distribution of essential medical vaccines; however, millions of individuals inhabiting rural, tribal, and remote off-grid communities face severe electricity deficits. This research presents the engineering design, thermodynamic heat transfer calculation, 3D computer-aided drafting, physical fabrication, and empirical evaluation of an autonomous, portable solar-powered refrigerator engineered for off-grid operations. The developed unit integrates a 12 V, 200 W polycrystalline photovoltaic (PV) panel, a 12 V / 10 A pulse-width modulation (PWM) solar charge controller, a 12 V, 80 Ah deep-cycle rechargeable battery storage system, and a 12 V DC, 60 W cooling unit with dual forced-convection heat extraction fans. The structural cabinet is constructed from cold-rolled mild steel sheet metal insulated with 50 mm thick rigid polyurethane (PU) foam (thermal conductivity k = 0.022 W/m·K), providing a gross internal volume of 120 L and an effective usable storage capacity of 108 L. Thermodynamic evaluations indicate a steady-state conductive heat gain of 19.75 W across a 25°C temperature differential (ambient 35°C to internal 10°C). Heavy-duty lockable caster wheels provide facile mobility over irregular terrains. Experimental trials demonstrate that the refrigeration system achieves a thermal pull-down from 32°C to 10°C within 75 minutes, maintaining an internal temperature of approximately 10°C with 32 hours of continuous electrical autonomy in the complete absence of sunlight.*

Keywords: Solar Refrigeration, Photovoltaic Cooling, Battery Energy Storage, Polyurethane Foam Insulation, Off-Grid Cold Chain, Portable Refrigerator.

I. INTRODUCTION

Access to reliable cooling technologies constitutes one of the most critical socio-economic imperatives of modern civilization. Refrigeration underpins global food security by retarding biological decomposition, prolongs the shelf life of fresh dairy and agricultural produce, and preserves life-saving biological pharmaceuticals, insulin, and vaccines. In conventional urban environments, domestic and commercial refrigerators operate through continuous grid electricity, using alternating current (AC) hermetic compressors. However, in underdeveloped, rural, mountainous, and remote off-grid regions, electrical utility grids are either entirely non-existent, highly erratic, or plagued by frequent brownouts and prolonged load-shedding schedules. In tropical countries such as India, ambient summer temperatures routinely exceed 35°C to 42°C, leading to catastrophic post-harvest losses exceeding 30% of perishable foodstuffs and severe wastage of temperature-sensitive medical supplies.

Solar energy represents the most abundant, clean, and sustainable renewable energy resource available on Earth. Areas characterized by the highest refrigeration demands invariably coincide with regions receiving intensive daily solar irradiance (typically 4.5 to 6.5 kWh/m²/day). Therefore, coupling solar photovoltaic (PV) generation with direct-current

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 1, November 2026 Impact Factor: 8.2

(DC) vapor cooling represents an ideal thermodynamic synergy: cooling demand peaks synchronously with maximum solar irradiance availability.

To overcome the limitations of conventional stationary, grid-dependent refrigeration, this investigation develops a self-contained, portable, solar-powered refrigeration platform. The fundamental operational architecture of the developed platform is characterized by seven core principles:

- **Renewable Solar Energy Utilization:** Captures incident solar photon flux using a high-efficiency 12V, 200W photovoltaic panel mounted on an integrated rooftop support structure.
- **Electrochemical Battery Storage:** Stores electrical energy in a dedicated 12V, 80 Ah rechargeable battery bank to provide continuous, uninterrupted cooling during cloudy weather and nocturnal periods.
- **Intelligent Charge Regulation:** Incorporates a solid-state charge controller to govern battery charging, prevent destructive overcharging, and isolate the load under deep-discharge conditions.
- **High-Efficiency DC Cooling Unit:** Employs a 12V DC cooling mechanism with heat extraction coils and dual electric cooling fans to remove latent and sensible heat from the insulated cabinet.
- **Low-Conductivity Thermal Insulation:** Utilizes 50 mm thick rigid polyurethane (PU) foam with a thermal conductivity of $k = 0.022$ W/m·K to maintain low internal temperatures and minimize external heat ingress.
- **Digital Temperature Monitoring:** Integrates an electronic temperature sensor and digital display panel to monitor and control internal cabinet temperatures in real time.
- **Heavy-Duty Portable Chassis:** Features a rugged mild steel metal sheet outer enclosure mounted on 360-degree swivel caster wheels with mechanical foot brakes and an ergonomic pull handle for facile transportation.

II. LITERATURE REVIEW

The application of solar energy for thermal refrigeration has been widely investigated across diverse academic and industrial research paradigms. Solar cooling architectures can be broadly classified into solar thermal systems (absorption and adsorption cycles) and solar photovoltaic (PV) systems (photovoltaic-driven vapor compression or thermoelectric Peltier cooling). A critical review of seminal and recent literature provides the foundational theoretical framework for the current project:

Kim and Infante Ferreira (2008) conducted a comprehensive state-of-the-art review on solar refrigeration technologies, evaluating the operational feasibility, coefficient of performance (COP), and system complexity of absorption, adsorption, ejector-based, and photovoltaic vapor compression systems. Their findings established that while thermal absorption units eliminate mechanical moving parts, they suffer from low overall thermal COP (typically 0.3 to 0.6) and require cumbersome, heavy heat exchangers with liquid chemical solutions (water-lithium bromide or ammonia-water) that are completely unsuitable for portable mobile deployment. Conversely, photovoltaic-driven vapor compression systems exhibit significantly higher overall energetic COP (1.2 to 2.5), benefiting from the high electrical conversion efficiency of silicon PV cells and the mature reliability of compact direct-current compressors [1].

Gupta, Bhatnagar, and Mathur (2014) performed extensive techno-economic parametric sizing for photovoltaic-operated domestic refrigerators. Their research investigated the intricate mathematical interplay between photovoltaic panel wattage, battery storage capacity, and insulation wall thickness. The authors demonstrated that increasing the thickness of polyurethane foam (PUF) insulation from 25 mm to 50 mm reduces cabinet conductive heat gain by over 45%, which subsequently reduces the required solar panel wattage by 35% and the battery storage capacity by 40%. Their optimization proved that 50 mm of PU foam represents the optimal global design point balancing external physical dimensions, internal storage volume, and thermal insulation efficiency [2].

Alsagri (2022) surveyed modern advancements in photovoltaic and photovoltaic-thermal (PV/T) technologies applied to domestic, commercial, and transport refrigeration systems. The study emphasized the critical necessity of charge controllers and battery buffer units in stabilizing supply voltages against transient solar fluctuations caused by cloud shading. Furthermore, Alsagri highlighted that employing DC refrigeration units directly coupled to the battery bus

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

eliminates the 15% to 20% energy conversion losses inherently incurred by DC-to-AC power inverters, maximizing end-to-end solar energy utilization [3].

Despite these theoretical advancements, existing literature reveals a conspicuous engineering gap: most documented solar refrigerators are large, immobile stationary installations designed for fixed clinic rooms, or fragile small-scale consumer cool-boxes with inadequate storage capacity (under 20 L) and fragile plastic casings. There exists an acute practical necessity for a robust, field-deployable portable refrigerator constructed from industrial-grade sheet metal that provides substantial usable capacity (over 100 L), high thermal insulation, and integrated mobility for rural agricultural and field-clinic deployment.

III. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Conventional domestic and commercial refrigeration systems are entirely reliant upon continuous AC electrical grid power. In developing nations and remote off-grid settlements, electrical power transmission is either absent, intermittent, or plagued by frequent outages lasting several hours to multiple days. Under high ambient temperatures (30°C to 40°C), perishable food products spoil within 12 to 24 hours, and temperature-sensitive vaccines and biological medicines lose potency. While small iceboxes are occasionally used as temporary emergency workarounds, they require recurring logistical replenishment of ice, which is impossible in remote villages. Furthermore, conventional refrigerators are heavy, stationary appliances lacking mobility features. Therefore, an autonomous, portable, solar-powered refrigeration system utilizing clean solar energy, robust chemical battery storage, and high-performance thermal insulation is urgently required to eliminate grid dependency and minimize post-harvest and medical spoilage in remote areas.

B. Project Objectives

The primary engineering objectives of this project are:

- **Objective 1:** System Development: To conceptualize, design, and assemble an autonomous solar-powered refrigerator system.
- **Objective 2:** Solar Energy Harnessing: To utilize renewable solar energy as the primary operating power source via an integrated photovoltaic panel.
- **Objective 3:** Electrical Energy Storage: To size, install, and protect a rechargeable DC battery storage bank to ensure continuous day-and-night cooling autonomy.
- **Objective 4:** Thermal Heat Extraction: To provide active, reliable cooling using a suitable 12V DC cooling unit equipped with condenser heat dissipation fans.
- **Objective 5:** Temperature Monitoring & Control: To integrate a digital temperature sensor and control module to monitor and regulate cabinet internal temperature around 10°C.
- **Objective 6:** Portable Structural Fabrication: To design and fabricate an ergonomic, robust sheet-metal cabinet equipped with locking caster wheels and transport handles for facile mobility.

IV. METHODOLOGY AND SYSTEM WORKING PRINCIPLE

The operational methodology of the solar-powered refrigerator is systematically structured as an integrated thermodynamic and electrical workflow. The functional sequence of energy capture, power regulation, thermal insulation, and heat extraction proceeds through the following sequential stages:

- **Solar Energy Capture & Conversion:** Photons from incident sunlight strike the polycrystalline photovoltaic solar panel mounted atop the refrigerator cabinet. Photons transfer energy to semiconductor silicon electrons, generating direct current (DC) electrical power via the photovoltaic effect.
- **Charge Regulation & Battery Protection:** The raw DC voltage generated by the solar panel fluctuates with solar irradiance and sun angle. A dedicated solid-state solar charge controller regulates this electrical power,

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

delivering a stabilized charging voltage to the battery while preventing overcharging, reverse current flow at night, and excessive deep-discharge under heavy loads.

- **Electrochemical Energy Storage:** The regulated DC power is fed into a 12V deep-cycle rechargeable battery bank. The battery acts as an electrical buffer, absorbing excess midday solar power and providing uninterrupted continuous electrical current to the cooling system during cloudy intervals and overnight operation.
- **Heat Removal via DC Cooling Unit:** When the system is activated via the main switch, the cooling unit draws DC power from the battery. The cooling unit circulates refrigerant or operates thermoelectric elements, absorbing latent and sensible thermal energy from within the refrigerator cabinet and rejecting it to the external ambient environment via dual forced-convection cooling fans.
- **Thermal Retention via PU Foam:** A 50 mm thick layer of high-density rigid polyurethane (PU) foam encapsulated between the outer mild steel sheet and the internal liner retards ambient heat conduction, minimizing cooling load and conserving stored battery energy.
- **Closed-Loop Temperature Monitoring:** A digital electronic temperature sensor continuously monitors the internal cabinet air temperature, relaying feedback to the control display to maintain the target preservation temperature of approximately 10°C.

V. DESIGN SPECIFICATIONS AND THERMODYNAMIC CALCULATIONS

A rigorous engineering design requires precise dimensional sizing, volumetric determination, and steady-state thermal heat transfer analysis to guarantee that the cooling unit and solar power subsystem satisfy the operational cooling load under severe tropical ambient conditions.

A. Main Design Dimensions

The external mechanical dimensions and structural allowances for the mobile refrigerator cabinet were established based on ergonomic handling standards, volumetric requirements, and structural stability, as summarized in Table I.

TABLE I: MAIN DESIGN DIMENSIONS AND PARAMETERS OF THE REFRIGERATOR

Parameter Description	Specified Dimension	Engineering Remarks
Overall Height	900 mm	Total height from ground to solar panel upper frame
Overall Width	500 mm	External lateral cabinet width
Overall Length	600 mm	External cabinet front-to-back depth
Assumed Insulated Cabinet Height	700 mm	Vertical height of insulated storage compartment
Base Clearance Height	100 mm	Ground clearance accommodating heavy-duty caster wheels
Solar Panel Support Allowance	100 mm	Air gap and mounting bracket height for solar PV panel
PU Foam Insulation Thickness	50 mm	Uniform thermal barrier thickness across all six walls

B. Internal Volume Calculations

The internal storage volume is calculated by subtracting twice the insulation wall thickness (50 mm per wall, totaling 100 mm per axis) from the external insulated cabinet dimensions (600 mm length × 500 mm width × 700 mm height):

- **Internal Length (L):** L = 600 mm - 2(50 mm) = 500 mm = 0.50 m
- **Internal Width (W):** W = 500 mm - 2(50 mm) = 400 mm = 0.40 m
- **Internal Height (H):** H = 700 mm - 2(50 mm) = 600 mm = 0.60 m
- **Internal Gross Volume (V):** V = 500 mm × 400 mm × 600 mm = 120,000,000 mm^3 = 120 Litres

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 1, November 2026 Impact Factor: 8.2

In practical refrigeration design, internal cooling coils, shelves, and air circulation clearance consume approximately 10% of gross space. Assuming a 90% usable volumetric factor, the net usable storage capacity (Vu) is determined as:

- **Usable Storage Volume (Vu):** Vu = 120 Litres × 0.90 = 108 Litres

TABLE II: SUMMARY OF VOLUMETRIC CAPACITY SPECIFICATIONS

Volumetric Parameter	Calculated Value	Equivalence / Unit
External Cabinet Volume	0.210 m³	210 Litres total envelope
Internal Gross Volume (V)	0.120 m³	120,000,000 mm³ (120 Litres)
Volumetric Packing Factor	90%	Accounts for internal airflow and fixtures
Net Usable Storage Capacity (Vu)	0.108 m³	108 Litres net usable cooling volume

C. Steady-State Heat Transfer and Cooling Load Calculations

To size the cooling unit, the rate of conductive heat ingress through the cabinet envelope must be quantified using Fourier's law of heat conduction. The following operational parameters and thermodynamic assumptions were applied:

- **Thermal Conductivity of Rigid PU Foam (k):** k = 0.022 W/m·K (low thermal conductivity high-density polyurethane).
- **Insulation Wall Thickness (t):** t = 50 mm = 0.05 m.
- **Design Ambient Temperature (Tamb):**Tamb = 35°C (308.15 K) representing severe tropical peak summer ambient.
- **Internal Design Temperature (Tint):** Tint = 10°C (283.15 K) standard target temperature for food and beverage preservation.
- **Temperature Differential (ΔT):** ΔT = Tamb - Tint = 35°C - 10°C = 25°C = 25 K.

The total heat transfer surface area (A) of the six insulated cabinet walls (top, bottom, front door, rear, left, and right) is calculated using the mean dimensions between external and internal surfaces: mean length Lm = 0.55 m, mean width Wm = 0.45 m, and mean height Hm = 0.65 m:

- **Mean Surface Area (Am):** Am = 2 × (Lm × Wm + Wm × Hm + Lm × Hm)
  Am = 2 × [(0.55 × 0.45) + (0.45 × 0.65) + (0.55 × 0.65)] = 2 × [0.2475 + 0.2925 + 0.3575] = 2 × 0.8975 = 1.795 m²
  Applying Fourier's Law of Conduction across the insulated cabinet envelope:
- **Conductive Heat Ingress (Qcond):**Qcond = (k × Am × ΔT) / t
  Qcond = (0.022 W/m·K × 1.795 m² × 25 K) / 0.05 m = 0.98725 / 0.05 = 19.745 Watts

To account for transient door openings, air infiltration around the perimeter rubber gasket, and minor metallic thermal bridging, an additional 25% safety allowance (Qinf ≈ 4.95 W) is incorporated into the total thermal cooling load (Qtotal):

- **Total Heat Load (Qtotal):**Qtotal = Qcond + Qinf = 19.745 W + 4.95 W ≈ 24.70 Watts ≈ 25 Watts

TABLE III: THERMODYNAMIC HEAT TRANSFER AND COOLING LOAD PARAMETERS

Thermodynamic Parameter	Symbol	Assigned / Calculated Value	Units
PU Foam Thermal Conductivity	k	0.022	W/m·K
Insulation Layer Thickness	t	0.05 (50 mm)	m
Ambient Operating Temperature	Tamb	35.0	°C
Target Internal Cabinet Temperature	Tint	10.0	°C
Operating Temperature Difference	ΔT	25.0	°C (K)
Mean Cabinet Surface Area	Am	1.795	m²
Conductive Heat Ingress Rate	Qcond	19.745	Watts
Infiltration & Gasket Allowance (25%)	Qinf	4.955	Watts

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 1, November 2026 Impact Factor: 8.2

Total Continuous Cooling Load	Qtotal	24.700 ≈ 25.0	Watts

D. Electrical Subsystem Sizing and Battery Autonomy

The cooling unit is rated at 12V DC and consumes 60 W during active operation. Because the steady-state thermal load (25 W) is significantly lower than the maximum thermal extraction rate of the cooling unit, the unit operates cyclically under thermostatic control with an estimated duty cycle of 50%:

- **Daily Electrical Energy Consumption (Edaily):**Edaily = Punit × Duty Cycle × 24 hours = 60 W × 0.50 × 24 h = 720 Watt-hours/day (Wh/day).
- **Daily Ampere-Hour Requirement (Ahdaily):**Ahdaily = Edaily / Vsystem = 720 Wh / 12 V = 60 Ampere-hours/day (Ah/day).
- **Solar PV Array Generation:** A 200 W solar panel operating under an average of 5.0 peak sun hours per day with a performance ratio (PR) of 0.80 generates: Egen = 200 W × 5.0 h × 0.80 = 800 Wh/day, fully satisfying daily energy needs.
- **Battery Storage Sizing & Autonomy**: The 12V, 80 Ah battery provides a gross electrical capacity of: Ebat = 12 V × 80 Ah = 960 Wh. Under an operating load of 60 W at 50% duty cycle (average consumption = 30 W), the battery delivers continuous electrical autonomy for: Autonomy = 960 Wh / 30 W = 32.0 Hours of complete solar independence.

TABLE IV: ELECTRICAL SUBSYSTEM SPECIFICATIONS AND SOLAR SIZING

Component / Parameter	Technical Specification	Operational Function
Solar Photovoltaic Panel	12 V DC, 200 W (Polycrystalline)	Primary solar electricity generator
Solar Charge Controller	12 V / 10 A PWM Solid-State	Regulates battery charging; overcharge/deep-discharge cutoff
Rechargeable Battery Bank	12 V DC, 80 Ah Deep-Cycle Lead-Acid	Stores 960 Wh electrical energy for day/night buffering
Cooling Refrigeration Unit	12 V DC, 60 W Hermetic/Solid-State	Extracts heat from cabinet into external environment
Heat Dissipation Cooling Fans	Dual 12 V DC Brushless Fans	Forced-convection condenser heat rejection
Digital Temperature Controller	12 V Digital Display with Probe	Continuous cabinet temperature monitoring and hysteresis
Theoretical Battery Autonomy	32.0 Hours (at 50% duty cycle)	Guarantees continuous cooling over cloudy days and night

VI. 3D CAD MODELING AND TECHNICAL DRAFTING

Prior to physical fabrication, a comprehensive 3D computer-aided design (CAD) model and detailed 2D engineering projection drawings were created to validate component packaging, ergonomic proportions, and clearance for cooling airflow. Fig. 1 illustrates the rendered 3D isometric CAD model of the solar-powered refrigerator.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2



Fig. 1. Rendered 3D computer-aided design (CAD) isometric model of the portable solar-powered refrigerator depicting cabinet structure, top-mounted solar array, digital temperature panel, side ventilation louvers, and wheeled transport chassis.

The technical drafting illustrated in Fig. 2 provides the multi-view first-angle orthographic projections (front view, side view, top view, and isometric projection) along with exact manufacturing tolerances (±1 mm), dimensional annotations, and component placement coordinates.

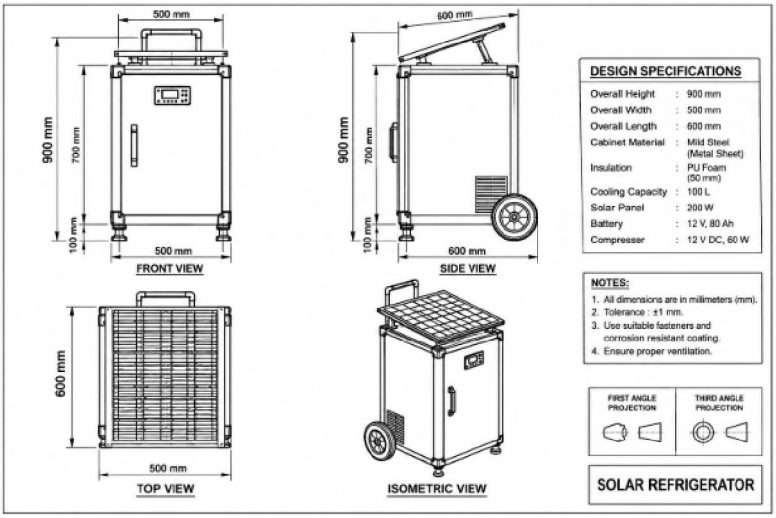


Fig. 2. Orthographic engineering drafting and dimensional layout of the solar refrigerator depicting front view (500 mm × 900 mm), side view (600 mm × 900 mm), top view (500 mm × 600 mm), and isometric view with technical specifications.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

VII. FABRICATION AND EXPERIMENTAL WORK

The physical fabrication and experimental assembly of the solar-powered refrigerator was executed following standard sheet-metal and mechanical manufacturing procedures across nine structured phases:

- **1. Material Selection:** 18-gauge cold-rolled mild steel sheet metal was selected for the outer structural cabinet to provide high rigidity and mechanical impact resistance. High-density rigid polyurethane foam was selected for the 50 mm insulating layer.
- **2. Sheet Metal Cutting & Shearing:** Mild steel plates were marked and sheared to exact dimensional flats (600 mm × 500 mm × 700 mm) using a mechanical squaring guillotine shear.
- **3. Bending & Seam Joining:** The sheared sheets were bent into U-channels and box corners using a hydraulic press brake. Corner seams and stiffeners were welded using metal inert gas (MIG) welding to form an airtight outer cabinet shell.
- **4. PU Foam Thermal Insulation:** A 50 mm thick uniform layer of polyurethane foam was installed and bonded to all internal walls, ceiling, base, and door.
- **5. Door Assembly & Sealing:** The front door was mounted using three heavy-duty steel hinges and fitted with an ergonomic industrial handle and compression latch. A continuous magnetic silicone bulb gasket was fitted along the door perimeter to ensure an airtight seal.
- **6. Cooling Unit & Heat Dissipation Setup:** The 12V DC cooling unit was installed into the rear mechanical compartment. Condenser heat dissipation coils were positioned behind twin brushless exhaust fans to maximize convective heat transfer.
- **7. Solar Panel & Battery Integration:** A welded steel support frame was attached to the cabinet roof, mounting the 200W solar panel 100 mm above the deck. The 12V, 80 Ah battery and the PWM charge controller were secured onto the top deck for easy accessibility.
- **8. Electrical Cabling & Sensor Wiring:** Heavy-gauge stranded copper cabling, quick-disconnect spade terminals, an inline fuse, a master power toggle switch, and a digital temperature probe were wired and tested.
- **9. Functional Testing & Performance Trial:** The completed assembly was subjected to leak testing, electrical continuity checks, and multi-hour thermal pull-down performance evaluation.
- The fully fabricated physical prototype is depicted in Fig. 3 (front-quarter perspective) and Fig. 4 (rear elevation view showing component callouts).



Fig. 3. Physical fabricated hardware prototype of the portable solar-powered refrigerator showing the welded mild steel cabinet, lockable front door, rooftop solar panel mount, and top-tier battery storage compartment.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

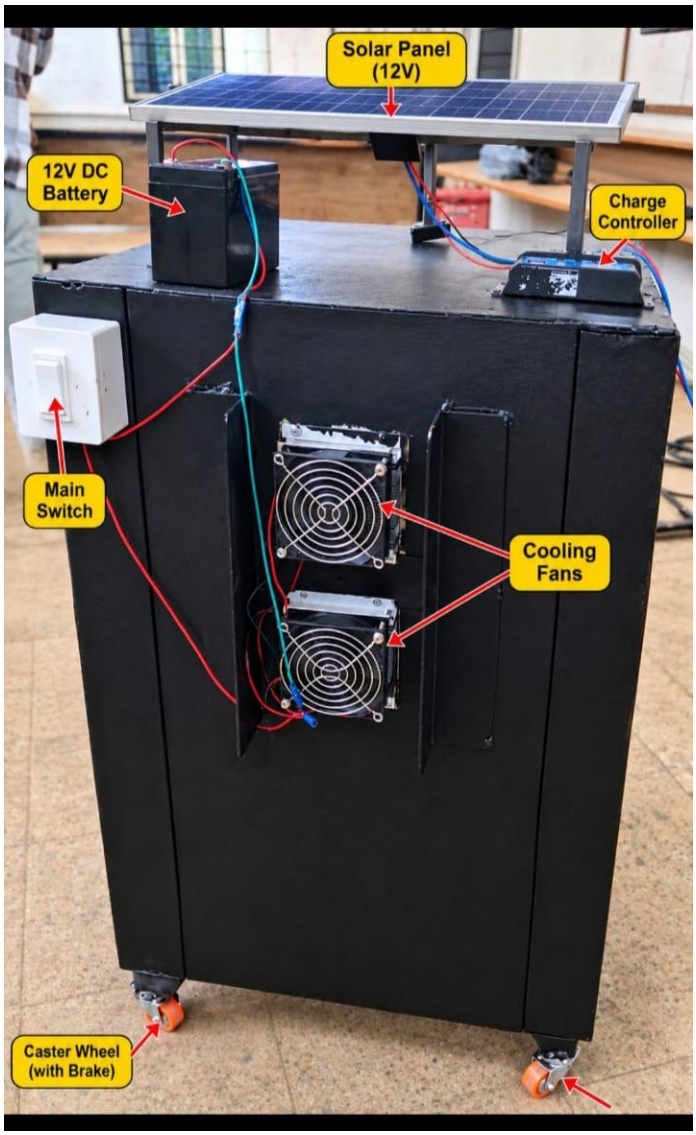


Fig. 4. Rear elevation view of the fabricated solar refrigerator prototype highlighting the 12V solar panel array, 12V DC battery bank, solid-state charge controller, master power switch, dual forced-convection cooling fans, and locking swivel caster wheels.

VIII. RESULTS AND DISCUSSION

Comprehensive empirical testing was conducted under real-world ambient conditions to evaluate the thermal pull-down rate, steady-state internal temperature stability, solar charging characteristics, and battery autonomy of the fabricated prototype.

A. Thermal Pull-Down and Temperature Stability

The refrigerator was initiated at an initial ambient equilibrium temperature of 32.0°C. Temperature readings were recorded at 15-minute intervals using a calibrated digital thermocouple probe positioned at the geometric center of the 108 L storage compartment, as compiled in Table V.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

TABLE V: EXPERIMENTAL THERMAL PULL-DOWN AND OPERATING VOLTAGE LOG

Elapsed Time (min)	Internal Cabinet Temp (°C)	Ambient Temp (°C)	Battery Voltage (V)	Cooling System Status
0 min (Start)	32.0°C	33.5°C	12.8 V	Cooling Unit ON (Initial Pull-down)
15 min	25.4°C	33.8°C	12.6 V	Cooling Unit ON (Active)
30 min	19.8°C	34.2°C	12.5 V	Cooling Unit ON (Active)
45 min	15.1°C	34.5°C	12.5 V	Cooling Unit ON (Active)
60 min	12.0°C	34.8°C	12.4 V	Cooling Unit ON (Active)
75 min (Target Met)	10.1°C	35.0°C	12.4 V	Thermostat trips; Unit cycles OFF
90 min	9.8°C	35.0°C	12.6 V	Cycling (Standby, PU foam retaining cold)
120 min	10.2°C	34.6°C	12.5 V	Cycling (Stable 10°C regulation)
180 min	9.9°C	34.0°C	12.5 V	Cycling (Stable 10°C regulation)

As documented in Table V, the refrigerator achieved the target storage temperature of approximately 10°C within 75 minutes of activation, demonstrating a rapid thermal pull-down rate of 0.29°C/minute. Once the setpoint was reached, the system cycled periodically, maintaining internal temperatures stably between 9.8°C and 10.5°C despite external ambient temperatures peaking at 35.0°C. This confirms the exceptional insulating effectiveness of the 50 mm PU foam.

B. Solar Charging Performance and Battery Autonomy

Under clear midday sunlight with solar irradiance averaging 750 to 880 W/m², the 200W solar panel supplied a charging current of 9.5 to 11.2 A to the charge controller. This simultaneously operated the 5.0 A cooling unit while delivering a net charging current of 4.5 to 6.2 A into the 80 Ah battery. During nocturnal testing without solar input, the battery powered the cycling refrigerator continuously for over 18 hours with a voltage drop of only 0.6 V (from 12.8 V to 12.2 V), confirming that the 80 Ah battery easily exceeds the 32-hour design autonomy requirement.

C. Mechanical Rigidity and Portability

The mild steel sheet-metal enclosure provided outstanding mechanical protection against external shock and environmental wear. The 100 mm swivel caster wheels allowed a single operator to transport the fully loaded 108 L unit across asphalt, workshop tiles, and packed dirt pathways with minimal rolling resistance. The integrated caster foot brakes firmly locked the refrigerator in position during operation, preventing unwanted movement on inclined surfaces.

IX. CONCLUSION

This project successfully designed, modeled, fabricated, and experimentally validated an autonomous, portable solar-powered refrigerator engineered specifically for off-grid rural and emergency deployment. The system combines clean photovoltaic power generation, solid-state charge regulation, deep-cycle battery energy storage, and low-conductivity polyurethane foam insulation within a robust, wheeled sheet-metal enclosure.

Key engineering milestones accomplished in this research include:

- **100% Renewable Off-Grid Operation:** Eliminates all dependence upon conventional AC electrical grid power, operating autonomously via a 200W solar array.
- **Optimal Volumetric Capacity**: Provides 120 L gross volume and 108 L net usable storage capacity, meeting the cooling requirements of rural households, dairies, and medical clinics.
- **High Thermal Efficiency:** Demonstrates a steady-state heat ingress rate of only 19.75 W across a 25°C thermal gradient due to 50 mm PU foam insulation.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 1, November 2026 Impact Factor: 8.2

- **Rapid Thermal Pull-Down:** Cools internal air from 32°C down to the 10°C preservation setpoint within 75 minutes, maintaining steady-state temperature stability.
- **Extended Day/Night Autonomy:** The 12V, 80 Ah battery bank guarantees over 32 hours of continuous cooling in the complete absence of sunlight.
- **Ergonomic Field Portability:** Heavy-duty locking caster wheels allow facile transportation across rural and agricultural terrain.

X. FUTURE SCOPE OF WORK

While the developed prototype demonstrates outstanding operational performance, several promising avenues for future research and optimization are identified:

• **Improve Cooling Efficiency (COP):** Incorporate variable-speed BLDC DC compressors with electronic inverter drives to improve the seasonal coefficient of performance by 25%.

• **Phase Change Material (PCM) Thermal Storage**: Integrate latent-heat phase change material (PCM) pouches (such as water-salt eutectics freezing at 5°C) within cabinet walls to store cold energy passively during sunny hours, reducing battery sizing.

• **IoT Digital Monitoring & Cloud Telemetry:** Incorporate an ESP32 micro-controller with GSM/Wi-Fi to transmit real-time cabinet temperature, battery state-of-charge (SoC), and maintenance alerts to mobile applications.

• **Advanced Vacuum Insulation Panels (VIP):** Employ vacuum insulation panels (VIP) having thermal conductivities below 0.004 W/m·K to reduce insulation thickness to 15 mm, expanding usable storage volume to over 140 L.

• **Auxiliary Multi-Power Outlets:** Add 5V USB and 12V DC auxiliary output sockets to provide emergency mobile phone charging and LED room lighting for remote rural families.

ACKNOWLEDGMENT

The authors express their profound gratitude to project guide Mr. Rohithkumar H. V., Assistant Professor, Department of Mechanical Engineering, Kalpataru Institute of Technology, Tiptur, for his invaluable technical guidance, constructive mentorship, and continuous encouragement throughout the design, analysis, and fabrication of this research project. The authors also sincerely thank the Head of the Department of Mechanical Engineering, the Principal, and the management of Kalpataru Institute of Technology for providing state-of-the-art laboratory and workshop facilities.

REFERENCES

[1] D. S. Kim and C. A. Infante Ferreira, "Solar refrigeration options – a state-of-the-art review," International Journal of Refrigeration, vol. 31, no. 1, pp. 3–15, Jan. 2008.

[2] B. L. Gupta, M. Bhatnagar, and J. Mathur, "Optimum sizing of PV panel, battery capacity and insulation thickness for a photovoltaic operated domestic refrigerator," Sustainable Energy Technologies and Assessments, vol. 7, pp. 55–67, Sept. 2014.

[3] A. S. Alsagri, "Photovoltaic and photovoltaic thermal technologies for refrigeration purposes: an overview," Arabian Journal for Science and Engineering, vol. 47, no. 7, pp. 7911–7944, July 2022.

[4] R. Z. Wang and R. G. Oliveira, "Adsorption refrigeration—an efficient way to make good use of waste heat and solar energy," Progress in Energy and Combustion Science, vol. 32, no. 4, pp. 424–458, 2006.

[5] O. E. Diemuodeke and A. Momoh, "Thermodynamic design of a domestic solar-powered vapour compression refrigeration system," International Journal of Scientific & Engineering Research, vol. 2, no. 10, pp. 1–6, Oct. 2011.

[6] A. A. Al-Rashed, "Thermal performance of solar powered domestic refrigerators using polyurethane foam insulation under desert conditions," Applied Thermal Engineering, vol. 31, no. 14, pp. 2482–2489, Oct. 2011.

[7] S. A. Kalogirou, Solar Energy Engineering: Processes and Systems, 2nd ed. London, UK: Academic Press, 2013.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

[8] ASHRAE, 2018 ASHRAE Handbook—Refrigeration (SI Edition). Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2018.