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Analysis of Refrigeration Units on Off-Grid PV/Wind Hybrid Systems on Navajo Reservation

Source: Solar Industries International [1]

PRESENTED BY

Manuelito Chief, Summer Technical Undergraduate Intern

Indian Energy Program

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Navajo Nation

- Covers 27,425 Square Miles
- 13 Full Service Grocery Stores
- 32% of households lack electricity [14]
  - 34,000 members without electricity
- 14.2% of Native American population lack access to electricity [13]
  - 75% of Native Americans without electricity live on the Navajo Nation

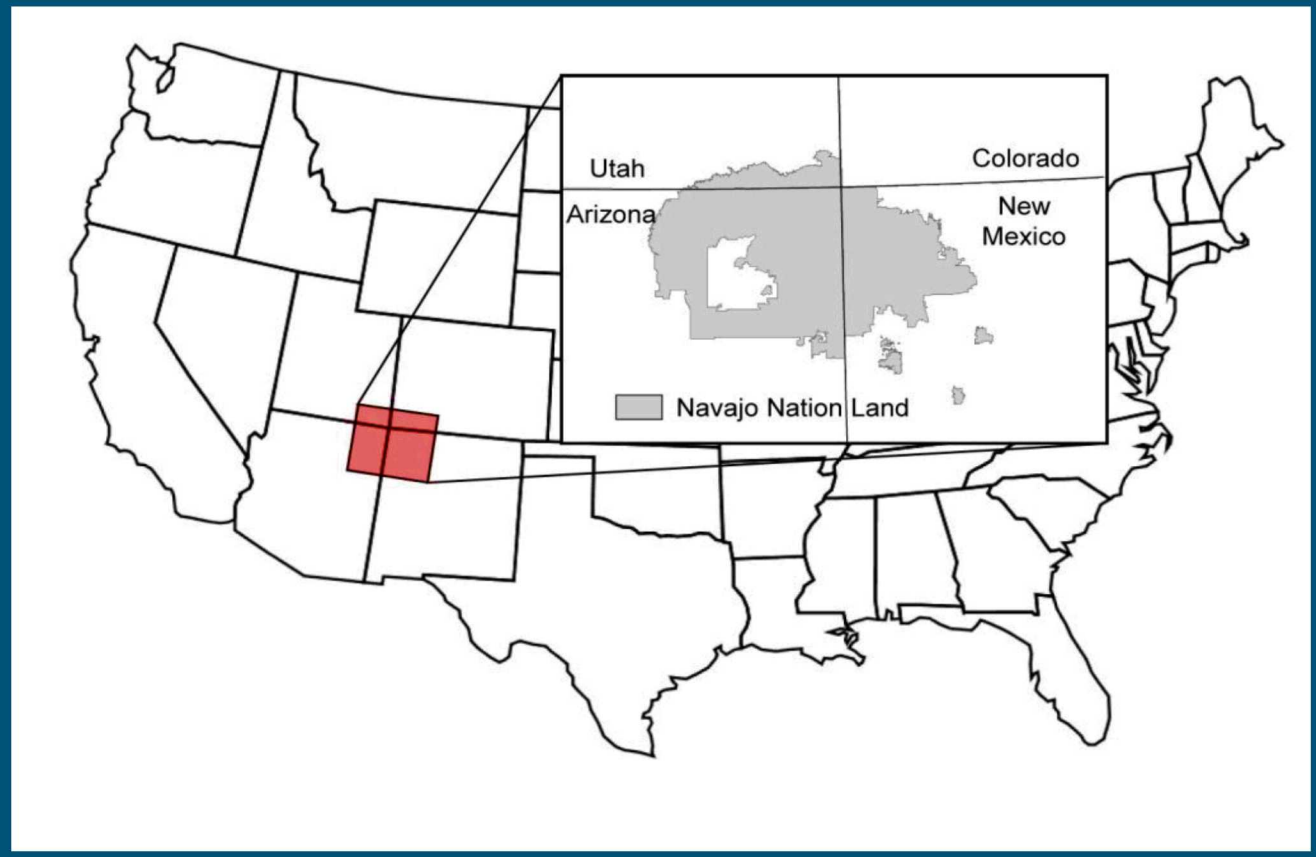

Fig 1: Source: IEEE Ocean Engineering Society. Credit: Cheryl Cary [2]

Navajo Tribal Utility Authority (NTUA)

- Established in 1959
- Provides Electricity, Water, Gas, Wireless Cell phones and Internet Telecommunications
- Services Off-Grid Residential Power (photovoltaics - PV) and Refrigerator Program beginning in 2002
  - Off-Grid System Configurations [3]:
    - 640W PV
    - 880W PV, 400W Wind
    - 1080W PV, 400W Wind w/ refrigerator – Added in 2010
    - 1800W PV, 400W Wind w/ refrigerator – Added in 2012
  - $75 or $100 per month based on established tariff

Fig 2: Source: Solar Industries International [1].

Problem Overview

- **Refrigeration is a basic need for all people.**
  - **There is limited access to fresh food on the Navajo Nation; high number of population without electricity.**
  - **Refrigerators allow Navajo residents to store foods for long periods of time.**
- **NTUA offered Energy Star rated refrigerators with 1080W hybrid and 1800W hybrid units (DOE EECBG funding).**
  - **Customers report Energy Star rated refrigerators have difficulty working with off-grid units.**
  - **NTUA General Manager asks Sandia National Labs to assist with this technical problem.**
- **There is a need to enhance the operation of these off-grid systems with high efficiency photovoltaic (PV) refrigerators or provide other solutions for NTUA and other tribes**

Off-Grid Photovoltaic (PV) / Wind Systems

- Photovoltaics system (PV only)
  - Provide power output during the day
- PV system with Wind Hybrid (PV + Wind)
  - Provide power output throughout the entire day including night
- PV system with Wind plus Storage (PV + Wind + Storage)
  - Provide smooth power output from PV and Wind
  - Store unused power

- Balance of the System (BOS) components
  - Inverter
    - For AC (alternating current) loads, inverter converts DC (direct current) to AC
  - Charge Controller
    - Used to recharge batteries
    - Add consistent output power

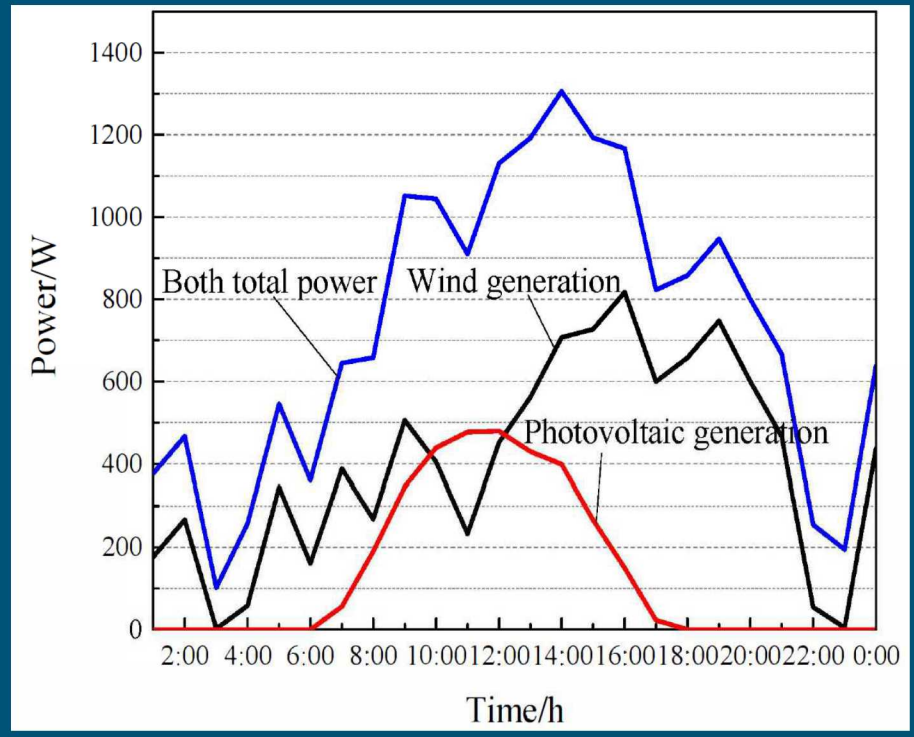

Fig 3: Output power from wind and solar PV generation over a 24-hour period in the winter [4]

Types of Refrigeration

Vapor Compression

- Single Speed AC Compressor
  - On – Off Cycle
  - Results in a surge in current to start the motor
  - Most off-the-shelf refrigerators use this method
- Variable Speed AC Compressor
  - Operate at different speeds
  - LG and Samsung have compressors that use this technology
- Variable Speed DC Compressor
  - Operate at different speeds
  - Eliminate the need for an inverter
  - Example: Danfoss (Secop) Compressor
  - DC refrigerators use this type of compressor
    - Sunfrost, SunDazer, Ecosolarcool, Unique, and Smad

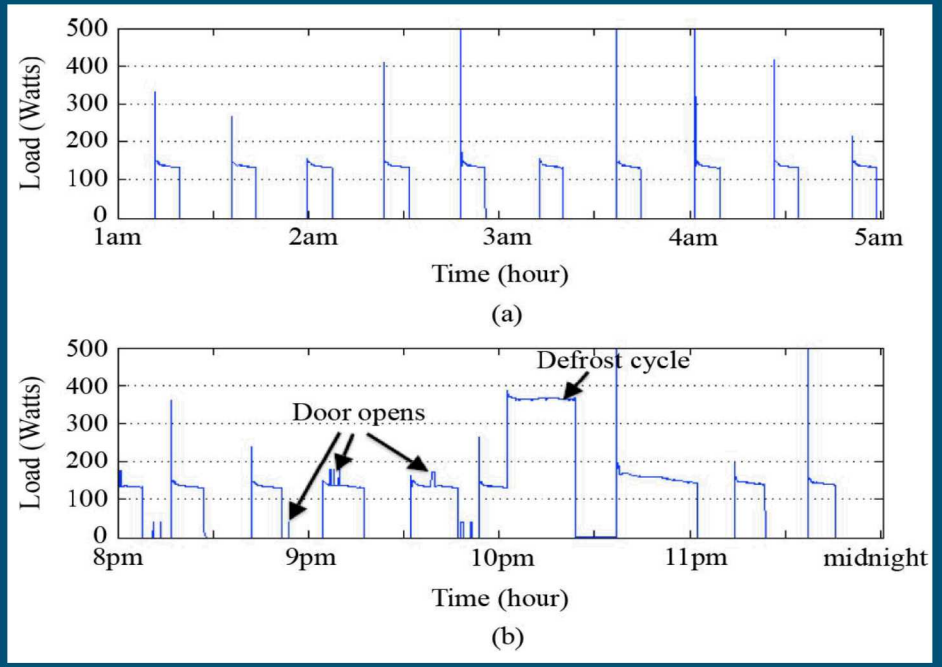

Fig 5: Load profiles of the top-freezer refrigerator unit: (a) no activity; and (b) with door opens and a defrost cycle. [6]

Conventional Refrigeration

Most refrigerators operate using a Vapor Compression cycle

- Refrigerate passes through phases transitions between liquid and gas
- See illustration on this slide

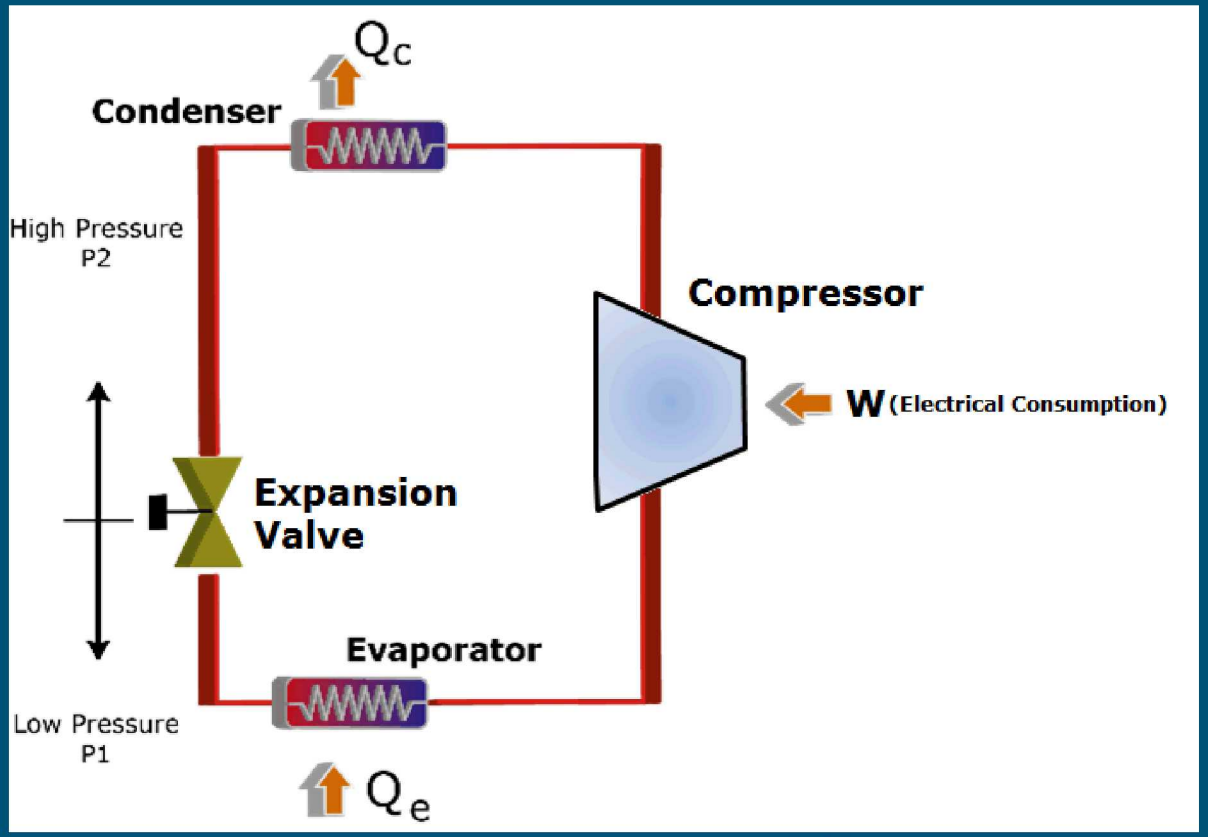

Fig 4: Operation of a vapor compression cycle [5]

Solar Refrigerator Conversion

In a research study, a conventional refrigerator was modified to serve as a solar refrigerator [7]

Modifications:

- AC compressor was changed to a Danfoss BD50F DC compressor
- Insulation was increased by 25 mm
- Inverter was eliminated

It was concluded:

- DC compressor can eliminate need for inverter
- Less power loss
- Solar utilization was increased

Type of Refrigeration

- Thermoelectric Refrigeration
  - Work using the Peltier Effect
  - Less mechanical parts. Requires fan for removing heat from plates
  - Can provide cooling and heating
  - Refrigeration temperature is depended on ambient temperature

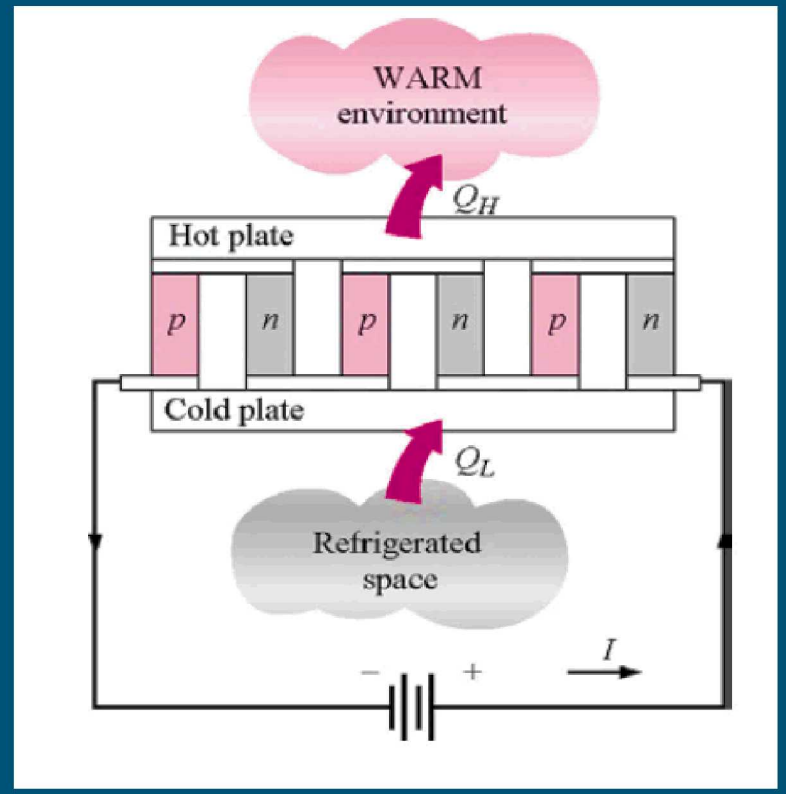

Fig 6: Operation of a thermoelectric refrigerator [8].

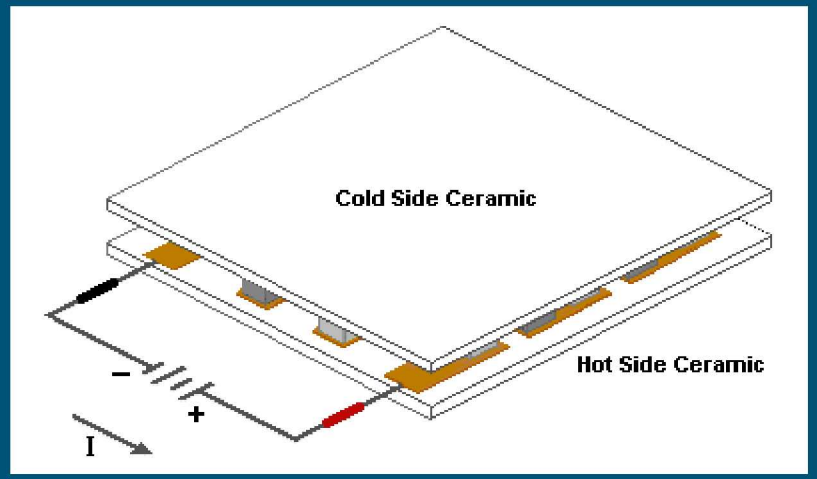

Fig 7: Operation of a thermoelectric refrigerator [9].

Other Types of Refrigeration

Vapor Absorption

- Works similarly to Vapor Compression Refrigerator
- Different in the method for changing gas back into a liquid which only requires heat
- Solar Thermal Refrigerator
  - Requires solar collectors

Propane Refrigerator

- Requires refilling of fuel
- Requires resident to travel long distance to refuel
- 10 cu. ft. propane refrigerator consumes about 1.5 lbs of fuel per day (547.5 lbs per year) [10].
- At $2.55 per gallon, there is a cost of $1395.87 annually for fuel [11].

Photovoltaic Power System Aspects to Consider

Areas to compensate:

- Batteries
  - Lead Acid (Flooded)
  - Absorbent Glass Mat (AGM)
  - GEL
  - Nickle Iron
  - Lithium Ion
  - Lithium Iron Phosphate
- Inverter
  - Output power
  - Output surge power
  - Output sine wave
    - Some inverters use an approximation of a sine wave
- Operation and Maintenance of the System
  - Load balancing / cycle of charge and discharge
  - BOS maintenance

Electrical Power System Design

Refrigerators require a surge each time the compressor operates. The power system can be modified to compensate for this characteristic.

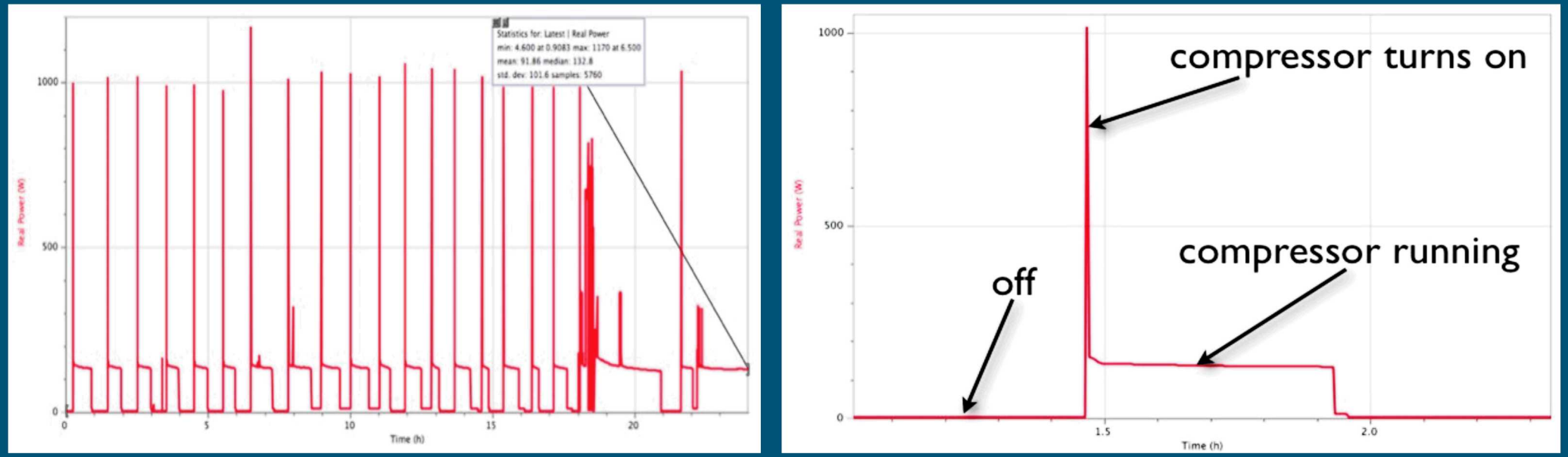

Fig 8: Left: Power consumption of a Hotpoint 15.6-cuft top freezer conventional refrigerator over a 24 hour period. Right: Graph of a single on-off cycle. [12]

Solar Refrigerators

Brand	Model	Type (R/F)	Size (CU. FT)	Power Requirement (W)	Whr Draw		Ahr Draw		Price	Vendor
					@32C/90F	@21C/70F	@32C/90F	@21C/70F		
SunFrost	RF16	Top Freezer R+F	14.3	-	700	480	58	40	$3,445	SunFrost
SunFrost	R10	Upright Type R	9.13	-	280	170	23	13	$2,085	SunFrost
SunDanzer	DCRF290	Top Freezer R + F	10.2	80	800	500	-	-	$1,399	SunDanzer
SunDanzer	DCR225	Chest Type R	7.9	80	198	-	17	8	$1,250	Northern Arizona Wind & Sun
SunDanzer	DCF225	Chest Type F	7.9	80	532	-	44	30	$1,250	Northern Arizona Wind & Sun
Ecosolarcool	ESCFR300DS	Chest Type R + F	10.5	80	*300 (Cooling)/570 (Freezing)		-		$1,300	Ecosolarcool
Ecosolarcool	ESCR260GE	Top Freezer R + F	9.2	72	*550		-		$1,299	Ecosolarcool
Unique	UGP-260L W	Top Freezer R + F	9.0	56	*572		*24		$999	Costco
Unique	UGP-290L1	Top Freezer R + F	10.3	56	*524		*24		$1,399	Sun-powergeneration
Smad	B071ZP2ZVC	Chest Type R + F	7.5	57	*530		-		$1,339	Amazon

Table 1: Comparison of DC refrigerators. *Ambient temperature @25C

Future Technologies to Consider

Super Capacitor

- To supply instantaneous power to loads that require surges of power
- Allow use of other loads such as water pumps and power tools in a small system

Smart Technology

- Smart Inverters
  - System Monitoring
  - Take electrical usage so customer can eliminate wasted energy
  - Identify problems in the system
- Smart Loads
  - Control loads
  - Load Prioritization/Scheduling

Proposed Solutions

1. Purchase solar refrigerators which are compatible with PV

   - Conventional refrigerators are not designed to be use with solar units
   - Lowest cost unit is $1000

2. Modify AC refrigerators to be a DC refrigerators

   - Install Danfoss BD50F DC compressor; labor to modify required
   - Insulation cannot be increased with existing AC refrigerators
   - Efficiency is improved
   - Inverter is not needed

3. Suggest Propane Refrigerators which don't require electrical power

   - Propane fuel approximately $1400 / year
   - Customers depend on fuel; need for transportation of fuel

Acknowledgements

- Department of Energy - Office of Indian Energy
- Sandia National Laboratories
- Navajo Tribal Utility Authority
- Sandra Begay

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