PV-Solar Chillers for Milk Cooling

BSW-Solar Special Exhibition „Off-Grid Power Solutions“
Case studies and technical solutions

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Institute Profile

Irrigation
- Precision irrigation and fertigation
- Sensors and control systems for irrigation scheduling

Energy
- Extraction of plant oil from Jatropha curcas
- Development of plant oil stoves
- Biogas as rural household energy
- Drying and conditioning of biogas digestate

Postharvest technology:
- Energy-efficient systems for high-quality fruit drying
- Solar drying
- Increasing energy efficiency in medicinal plant drying
- Non-invasive quality assessment

Solar Refrigeration:
Design methodology to facilitate economical evaluation of solar refrigeration as businesses opportunity in rural areas.

In collaboration with:
Research Group of Applied Thermal Engineering

https://www.uni-hohenheim.de/einrichtung/fg-agrartechnik-in-den-tropen-und-subtropen
Motivation

Cost competitive cooling technologies are able to improve economical development of rural areas of the tropics by adding value to perishable agricultural and animal produce.

In many countries, the evening milk cannot be properly processed because it is highly perishable and cannot be kept fresh until the next morning.

Conventional vapor-compression cycles refrigeration systems driven by solar energy are becoming more attractive thanks to PV cost reduction.

A design methodology for solar chillers is needed for the assessment of business opportunities at different climatic conditions and demand scenarios.
Solar Cooling System

- PV: 70-180 Wp
- Battery: 800-2000 Wh
- Chiller: (Model: Steca-PF166) 166 L
- Working Temp. -20 to 12 °C
- System Cost: 1000 – 1500 €
Milk cooling requirements

Milk Quality improves by:

• Conservation temperature:
  Under 12°C for one day conservation
  Under 8°C for two days conservation

• Fast cooling after milking:
  Under 12°C after 2 hours
  Under 8°C after 4 hours
Testing Bench

Measurements under real conditions:

- Emulation of PV Power and Ambient Temperature
- Based on Meotonorm Weather data
- Temperature sensors for cooling process
- Fridge electrical consumption
- Operation strategy (Compressor Speed, Fan, Cold Storage)

✓ Location
✓ PV Size
✓ Battery Capacity
Experimental comparison of natural convection, *forced convection* and water bath:

- **Testing fluid:** Water
- **Chiller load:** 3 liter
- **Cooling temperature:** 4°C
- **Forced convection needed to meet cooling requirements**
- **Low influence of fan position and power (over 1.5 Watt)**
Refrigeration Load Measurements

Meets cooling requirements with:

- Forced convection during cooling process.
- Maximal load of 12 Liter simultaneously
- Container volume under 2 liter
Simulation model

Cooling Scenario

- Cooling Method (Forced Convection)
- Container volume (1.5 PET)
- Refrigeration load and exchange times (10 L at 8 am + 10L at 8 pm)
- Location (Outdoors/Indoors)

Real Conditions Measurements (at different Ambient temperatures)

Fridge + Battery, (Matlab)

PV Simulation (TRNSYS)

Weather Data (Meteonorm)

Optimizer (Matlab)

Economical Optimum Energy Supply
PV (2€/Wp) – Battery (0.2€/Wh)

• PV Module: 5-Parameter TRNSYS Model based on data sheet (Solar World, SW Poly RNA)

• Lead Battery: Consider aging, self discharge and internal resistance based on data sheet (Intact, Block-Power)
Annual Simulation

System after 8 Years located outdoors at Havana – PV:120 Wp Battery: 1500 Wh

Battery aging due to more intensive use

Compressor electrical energy [Wh/day]

Fridge Temperature [°C]

Ambient Temp

Cooling Load: 15 Liter/day at 30°C

Cooling Load: 5 Liter/day at 30°C

Daily Irradiation

Cooling Load: 15 Liter/day at 30°C

Cooling Load: 5 Liter/day at 30°C

System after 8 Years located outdoors at Havana – PV:120 Wp Battery: 1500 Wh
**Solar energy supply optimization**

**Refrigeration load variation:** located outdoors at Havana

![Diagram showing solar power supply optimization](image)

- Optimized for 8 Years of use (incl. Battery aging)
- Basis System cost: 1000€
- Variable System Cost: 30€/liter/day
**Temperature sensitivity**

**System after 8 Years located at Havana**

- Internal Temperature (4-12 °C)
- Refrigeration Load: 10 Liter/day
- Outdoors

**Cooling Temp.**

- Internal Temperature (4-12 °C)
- Refrigeration Load: 10 Liter/day
- Cooling Temp. : 4°C

**Cost Sensitivity: -32€/°C Ti**

- Cycle = 90 Wp Bat=858 Wh - Max. Power=37 W
- Cycle = 120 Wp Bat=1164 Wh - Max. Power=51 W
- Cycle = 150 Wp Bat=1553 Wh - Max. Power=67 W

**Temperature sensitivity**

**System Cost €**

- Outdoor - System Cost= 1047€
- PV=90 Wp Bat=858 Wh - Max. Power=37 W
- PV=60 Wp Bat=745 Wh - Max. Power=22 W
- PV=90 Wp Bat=876 Wh - Max. Power=28 W

- Indoor at 20°C - System Cost= 962€
- PV=60 Wp Bat=745 Wh - Max. Power=22 W
- PV=25°C - System Cost= 1059€
- PV=90 Wp Bat=876 Wh - Max. Power=28 W

**Cost Sensitivity: 19€/°C Text**

- Cycle = 90 Wp Bat=858 Wh - Max. Power=37 W
- Cycle = 60 Wp Bat=745 Wh - Max. Power=22 W
- Cycle = 90 Wp Bat=876 Wh - Max. Power=28 W

- Cycle = 20°C - System Cost= 1059€
- PV=90 Wp Bat=876 Wh - Max. Power=28 W
Location sensitivity

System after 8 Years located outdoors (Cooling load 10 liter/day at 30°C)

- High temperatures increase cooling power
- Tropical weather conditions increase battery cost

Sun Irradiation (Meteonorm)

Ambient Temperature (Meteonorm)
Economical evaluation

System cost estimations (location Kisangani, T₀=4°C, placed outdoors)

Added value:
- Milk waste reduction (evening milk)
- Smallholder farms growth
- More efficient milk processing
- Market flexibility (Milk collection centers)

Investment
100€ Invest per liter/day Capacity.

Profitability case:
Payback period set to max. 5 years (Interest year rate of 10%)
Battery lifetime: 5 years
PV/Chiller Liftetime: 15 years
Usage of Fridge 75%

Minimal added Value: 5 Euro cent / Liter Milk
Conclusion

• The studied chiller is able to cool down **about 12 L milk simultaneously by using forced convection** (1.5W fan) meeting the requirements. (estimated daily load 25 L).

• A **simulation model based on real conditions measurements**, facilitates fundamental **optimisation of the solar system** (50% of the investment).

• The profitability of **business opportunities with stand-alone refrigeration in the agricultural sector** depends on Location, cooling scenario and added value of the conserved milk.

• **Further Work :**
  1) **Cold Storage** possibilities to improve cost efficiency and reliability.
  2) **Evaluation of milk Quality improvement** and marketing chain.
  3) Assessment of performance and **acceptability under real field conditions**.
Thank you for your attention!

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