UNIVERSITY OF HOHENHEIM

Solar Cooling Systems for agricultural value-chains in the Tropics and Subtropics

Institute of Agricultural Engineering in the Tropics and Subtropics
University of Hohenheim in Stuttgart – Germany

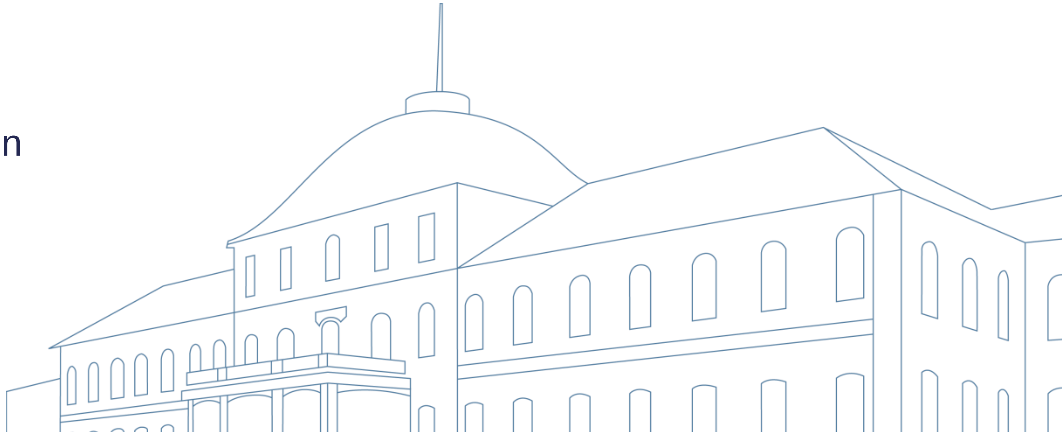
Dr. Victor Torres-Toledo
Garbenstr. 9, 70599 Stuttgart
Tel: +49 711 459-22840
Victor.torrestoledo@uni-Hohenheim.de
https://agrartechnik-440e.uni-hohenheim.de/en/1670

Auftaktveranstaltung zur Informationsreise Algerien

IHK Haus der Wirtschaft Karlsruhe, 09. April 2019

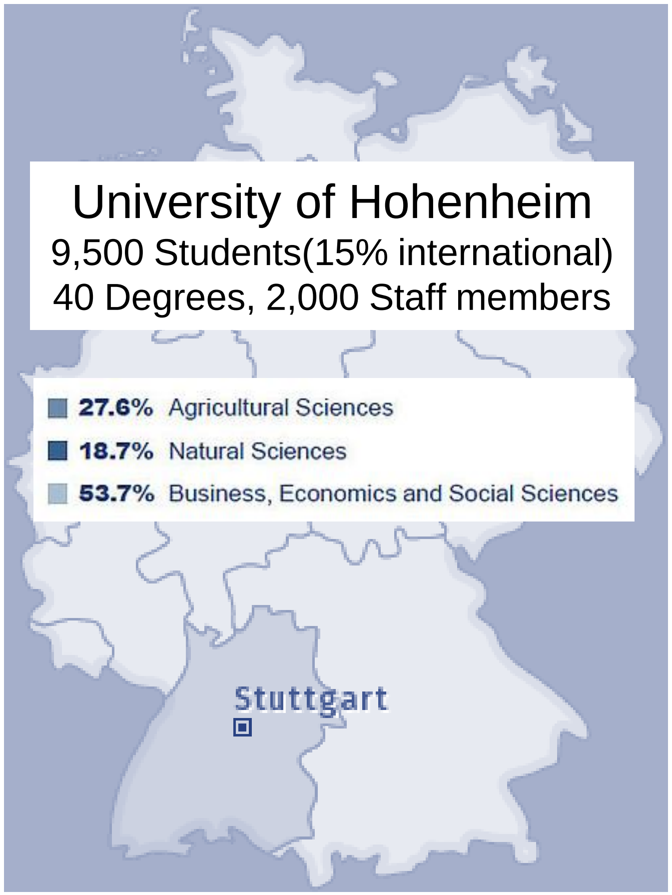
Bundesministerium für Wirtschaft und Energie

MITTELSTAND GLOBAL EXPORTINITIATIVE ENERGIE



UNIVERSITY OF HOHENHEIM

Who are we?



University of Hohenheim
9,500 Students(15% international)
40 Degrees, 2,000 Staff members

Tropics/Subtropics group of the Institute of Agricultural Engineering

- 5 Departments (Professors)
- 150 Staff members

<u>Attached to the multidisciplinary:</u>
Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg)

- 10 Departments (Professors)
- 100 Researchers

Tropics/Subtropics group (Prof. Dr. Joachim Müller)

- Solar Drying
- Irrigation (Solar)
- Plant oil extraction (Solar)
- Use of biogas/biomass
- Postharvest technologies
- **Solar cooling**




Prof. Dr. Joachim Müller

20 PhD Students
6 Post. Docs.
5 Technical staff
2 administrative staff

From 15 countries!

Facilities of the Institute of Agricultural Engineering

Metal Workshop

Wood Workshop

Electric/Electronic

Laboratories

Research hall

Greenhouse

Solar cooling testing facilities

Weather profile

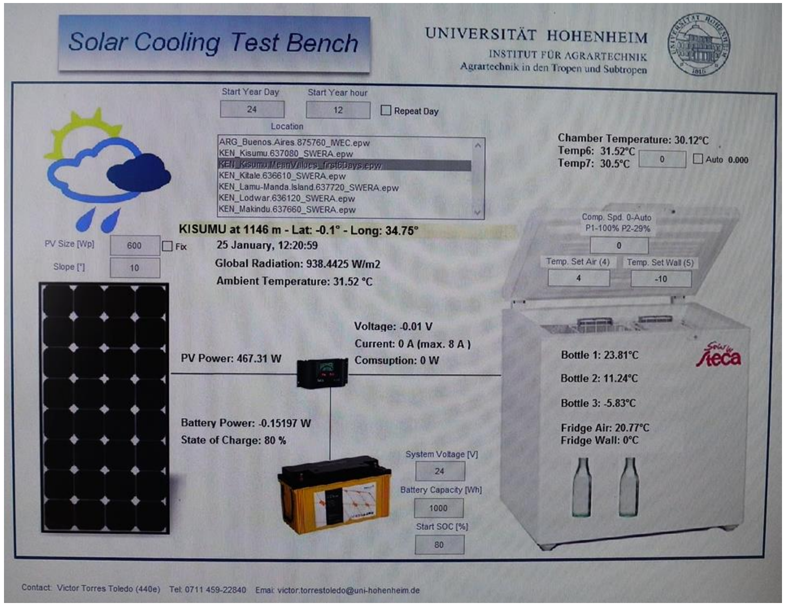
⇩

Climate chamber

Solar Power profile

⇩

PV Simulator



Solar cooling team

Victor Torres-Toledo

Julian Krüger

Farah Mrabet

Muaz Bedru

Ana Salvatierra-Rojas

Juliet Kariuki

Florian Männer

Kilian Blumenthal

Motivation of cooling for food value chains

- Saves nutritional value and taste
- Minimizes mass loss and slows ripening
- Controls rate of growth of microorganisms

Business opportunities

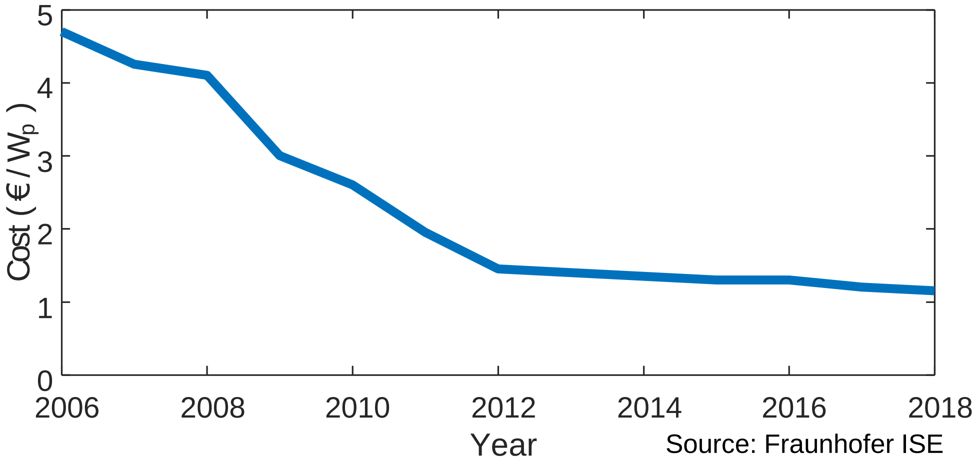
- Helps to reduce postharvest losses
- Increases product quality
- Gives access to new markets

Challenges in rural areas

- Low quantities
- Limited electricity access
- High ambient temperatures
- Lack of infrastructure

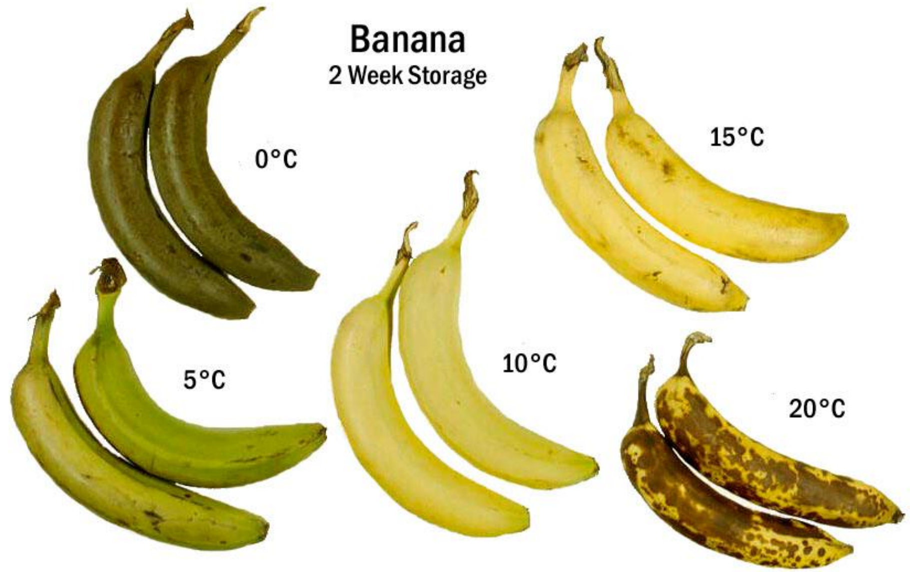
Opportunities

- Cost reduction of PV panels



Source: Fraunhofer ISE

Chilling damage



Source:UC Davis Postharvest Technology Center, University of Delaware

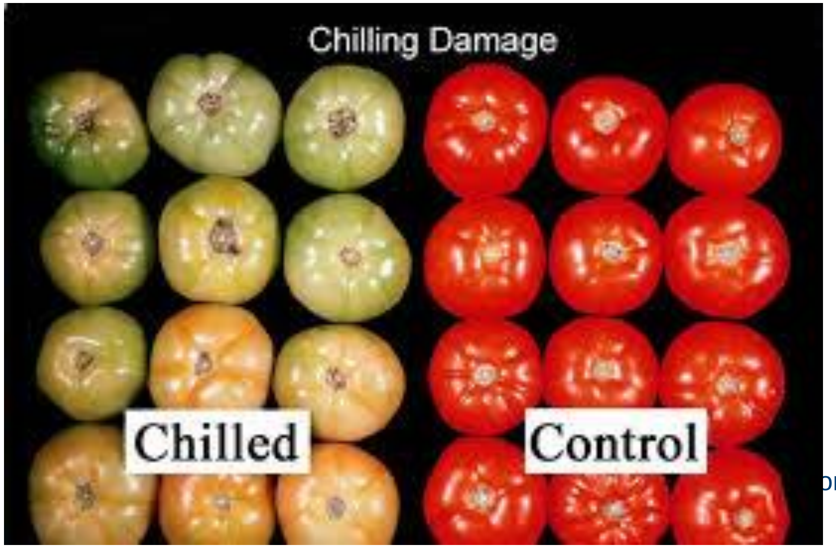
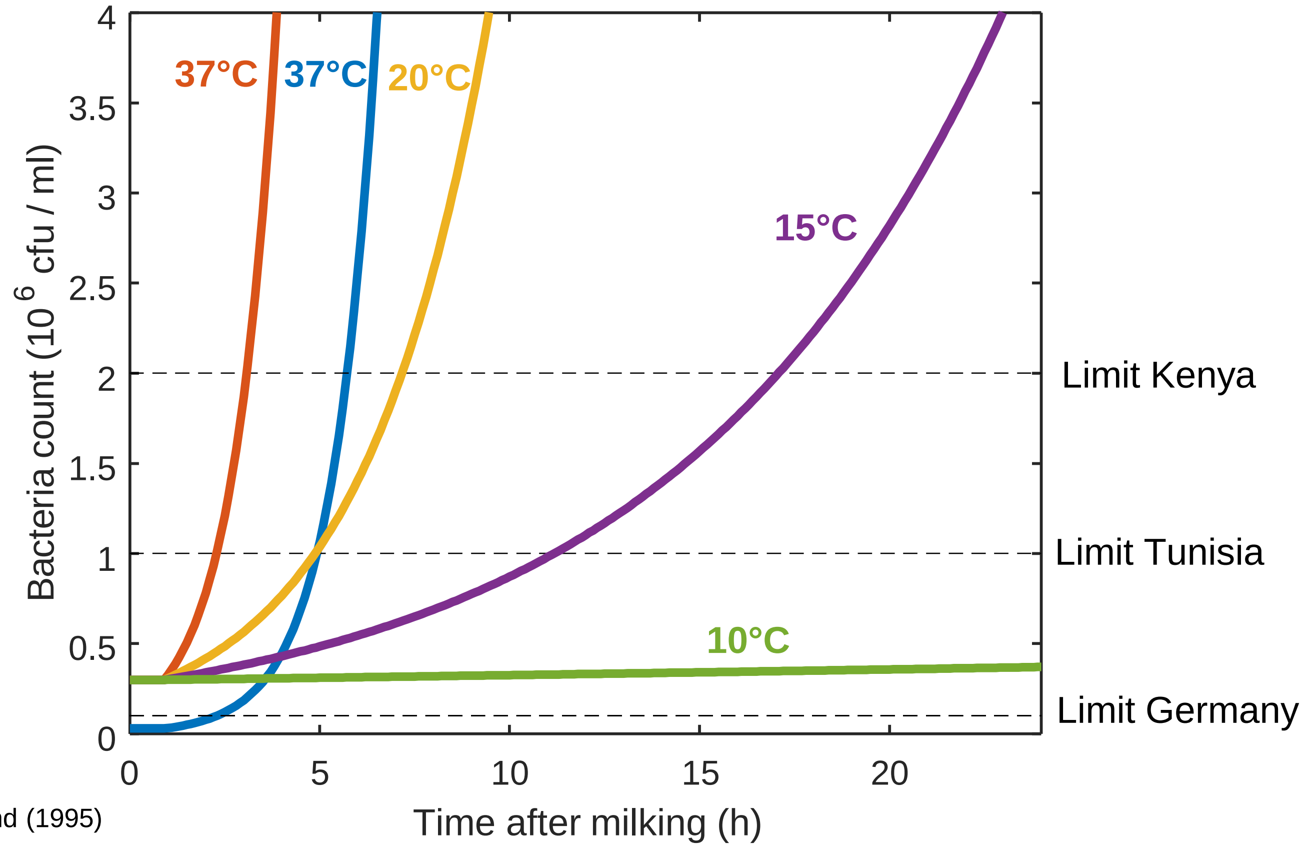


Table 5.2 Fruits and vegetables susceptible to chilling damage (sources: Hardenburg et al., 1986; IIR, 2000; McGlasson et al., 1979; McGregor, 1989)

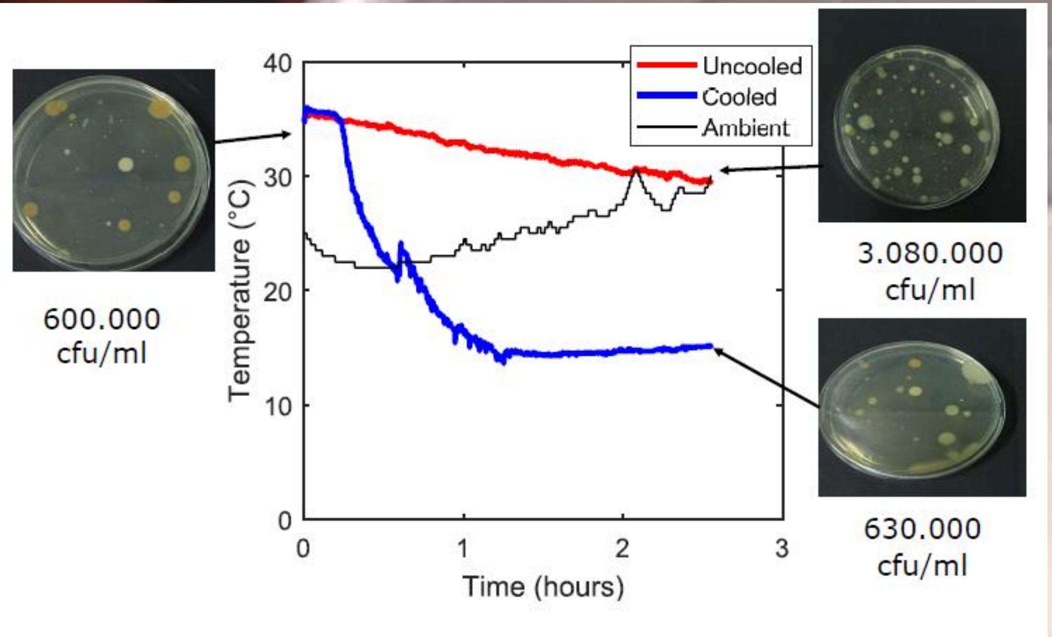
Commodity	Lowest safe temperature (°C)	Damage
Apples		
certain varieties	1–2	Internal browning, brown core
Avocados		
West Indian	11	Pitting, internal browning
Other varieties	5–7	Pitting, internal browning
Bananas	12–13	Dull color, blackening of skin
Beans	7–10	Pitting and russeting
Cucumbers	7–10	Pitting, water-soaked spots, decay
Grapefruit	7	Scald, pitting, watery breakdown, internal browning
Lemons	13–14	Internal discoloration, pitting
Mangoes	5–10	Internal discoloration, abnormal ripening
Melons		
Cantaloupe	7	Pitting, surface decay
Honeydew	4–10	Pitting, surface decay
Watermelons	2–4	Pitting, objectionable flavor
Oranges	3	Pitting, brown stains
Papaya	6	Pitting, water soaking of flesh, abnormal ripening
Potatoes	3–4	Mahogany browning, sweetening
Tomatoes	7–10	Water soaking and softening

Milk Cooling

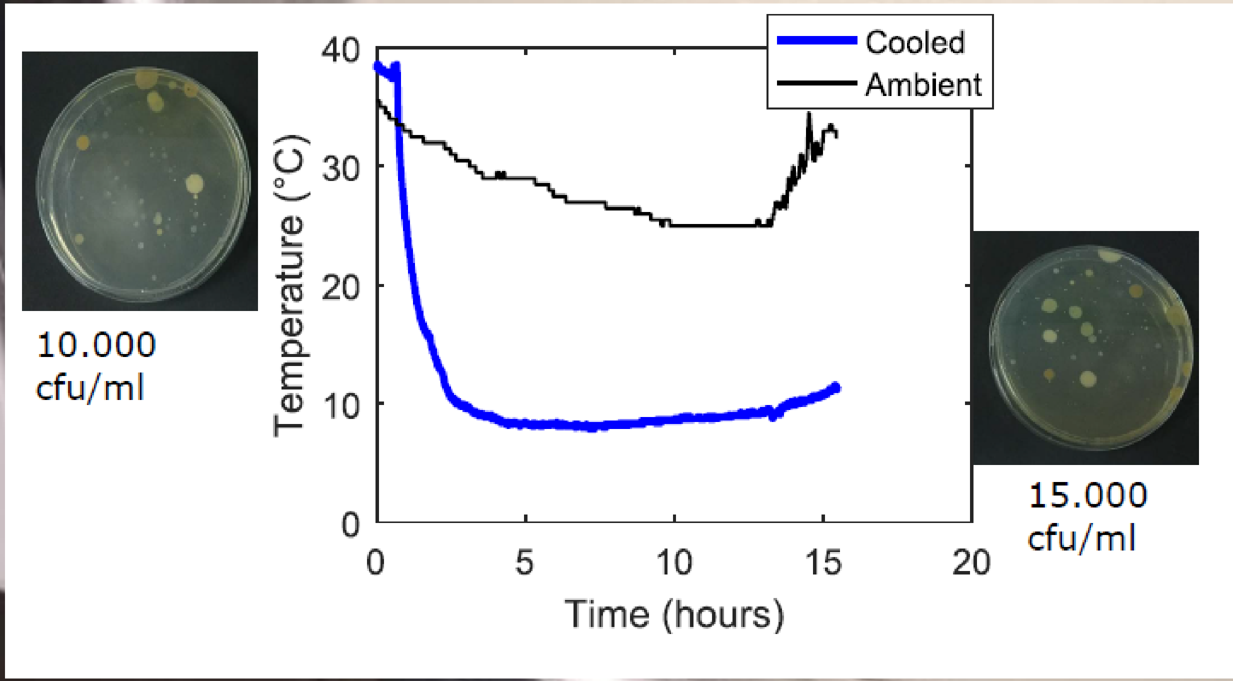
- Raw milk has around 37°C after milking
- Highly perishable due to rapid bacteria growth
- Preservation of milk quality through reduction of temperature



Source: Modified from Bylund (1995)

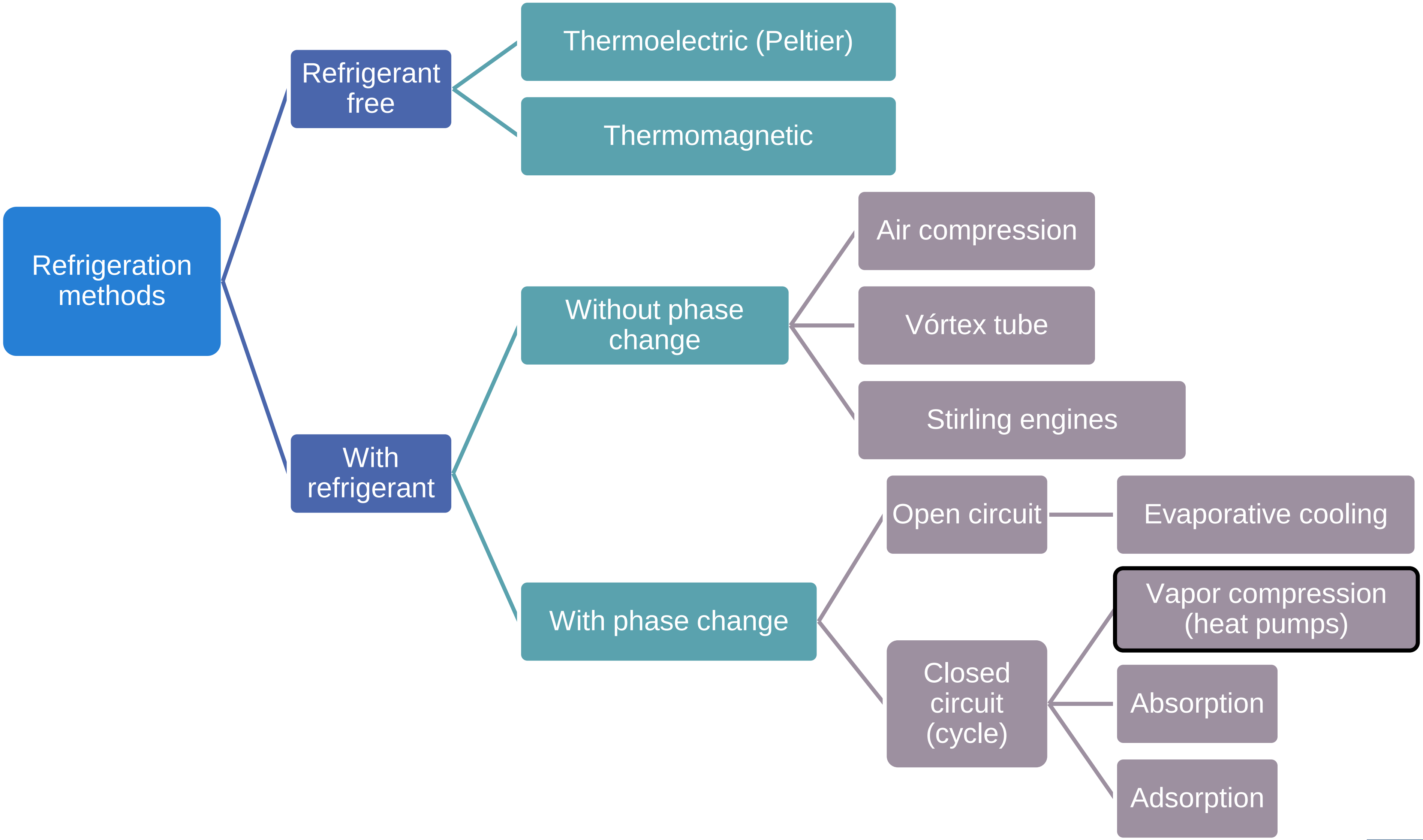


5 Times better quality after 2.5 h



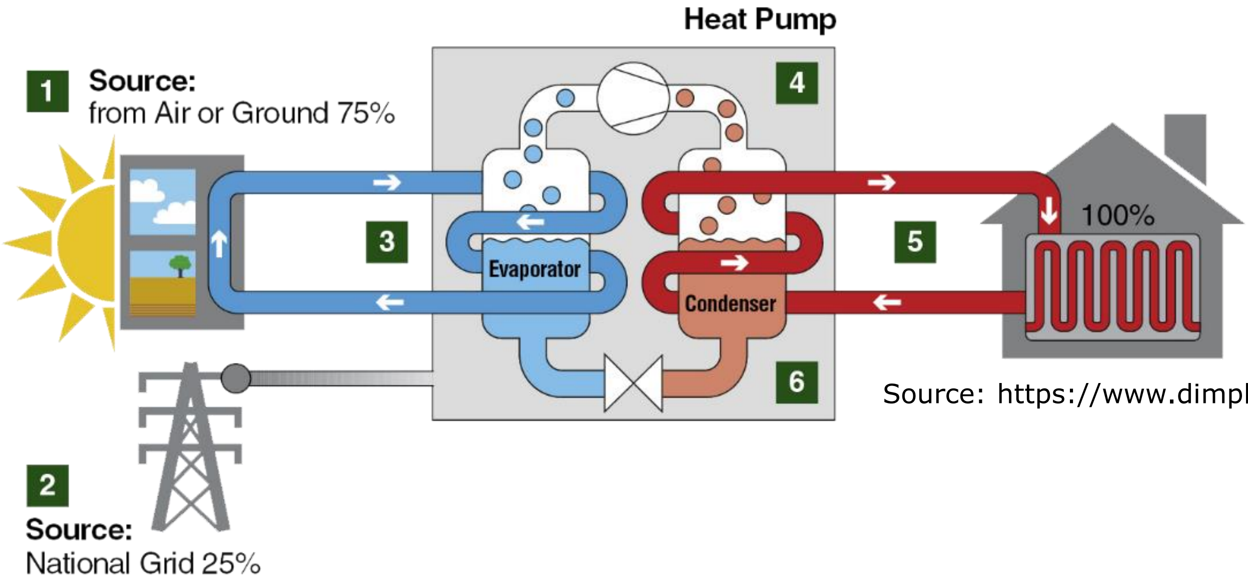
Effective quality preservation up to 16 h!

Refrigeration methods



Solar Cooling Unit

Coefficient of Performance (COP)



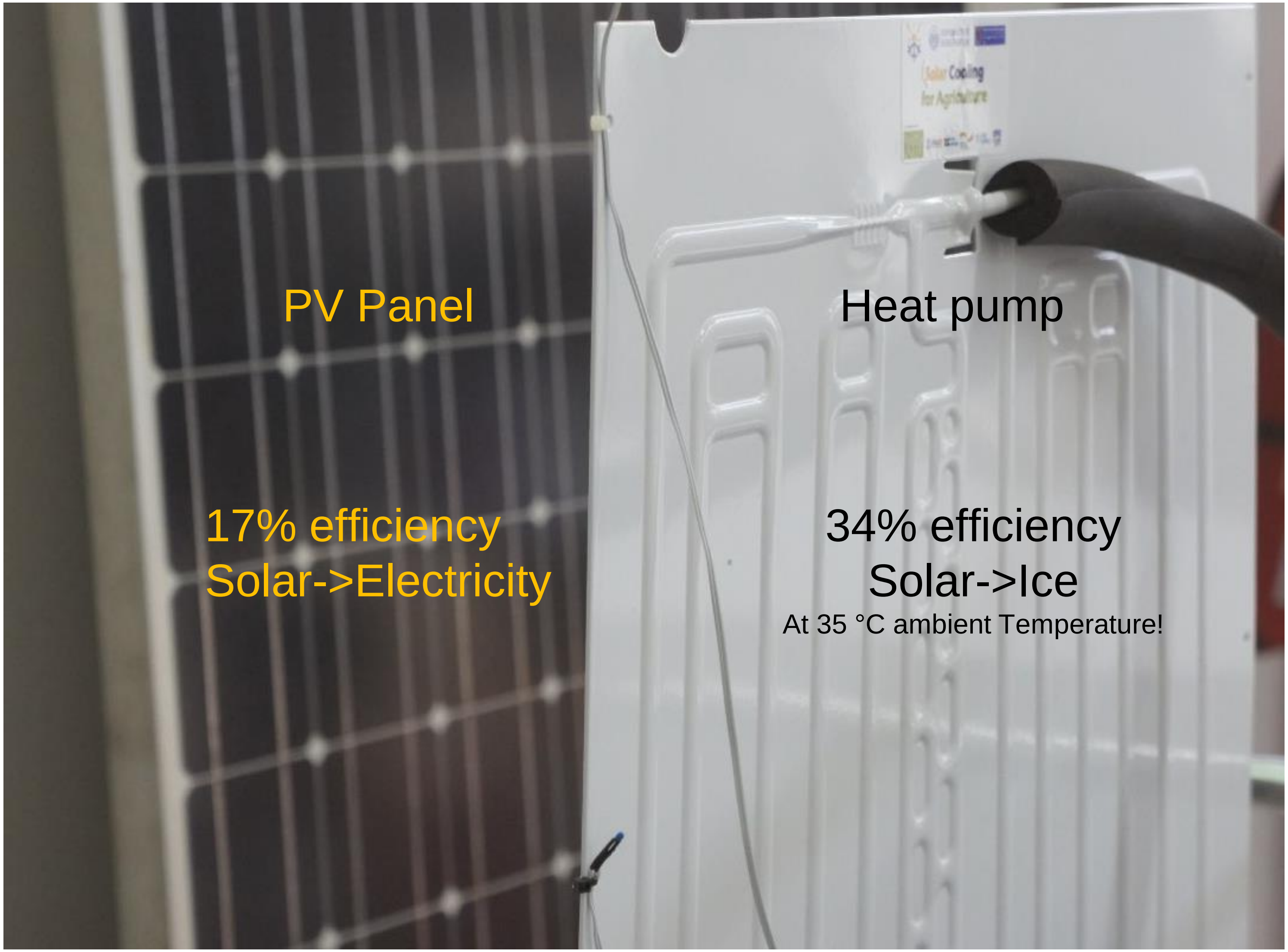
Source: https://www.dimplex.co.uk

- **COP Refrigeration cycle (real) ***

		T warm (°C)		
		20	**30**	**40**
T cold (°C)	**4**	2.6	2.1	1.8
	-10	1.6	1.4	1.1

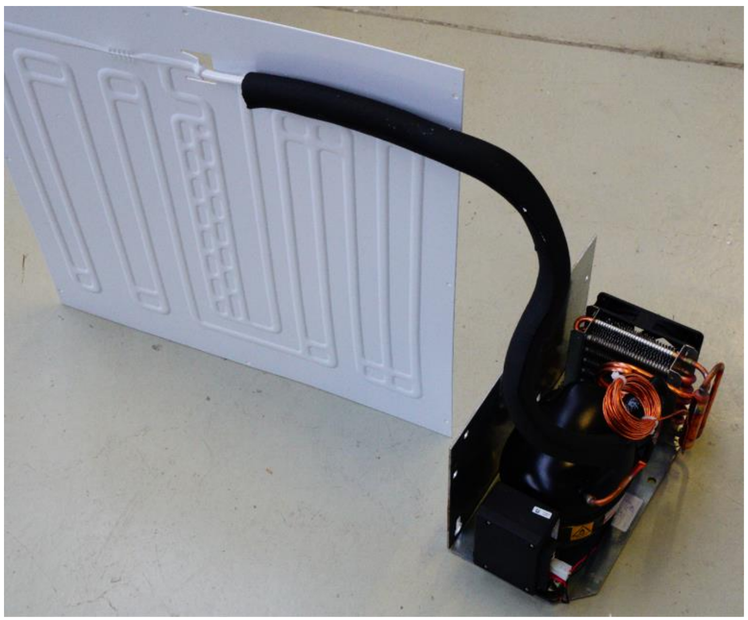
* Different for each refrigeration system

Solar cooling with vapor compression heat pumps

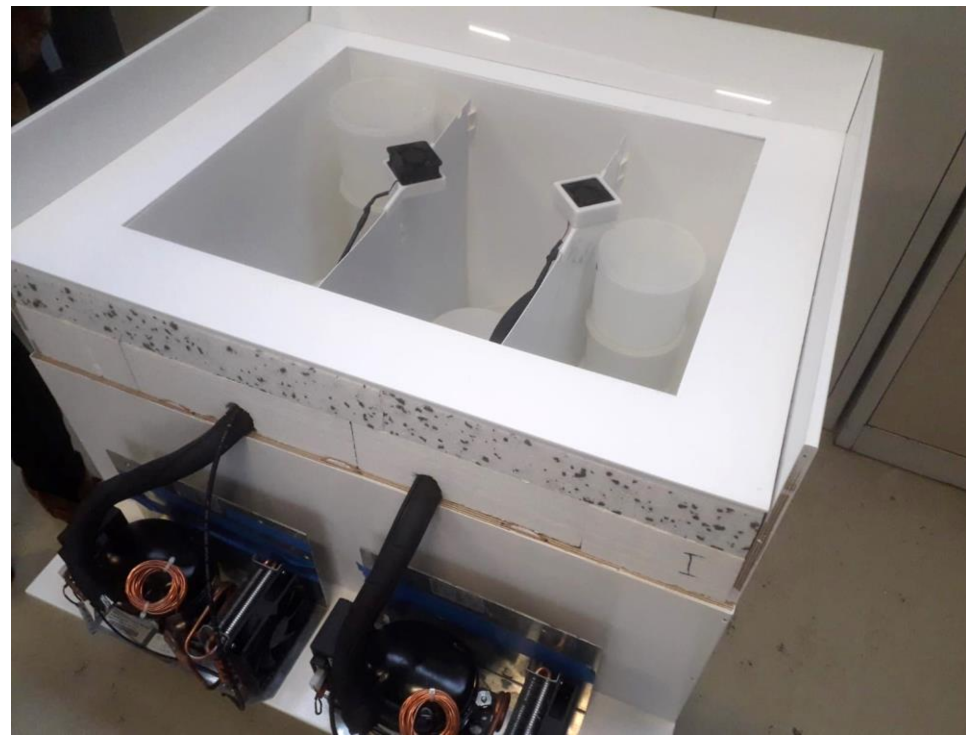


Promote key components instead of key systems

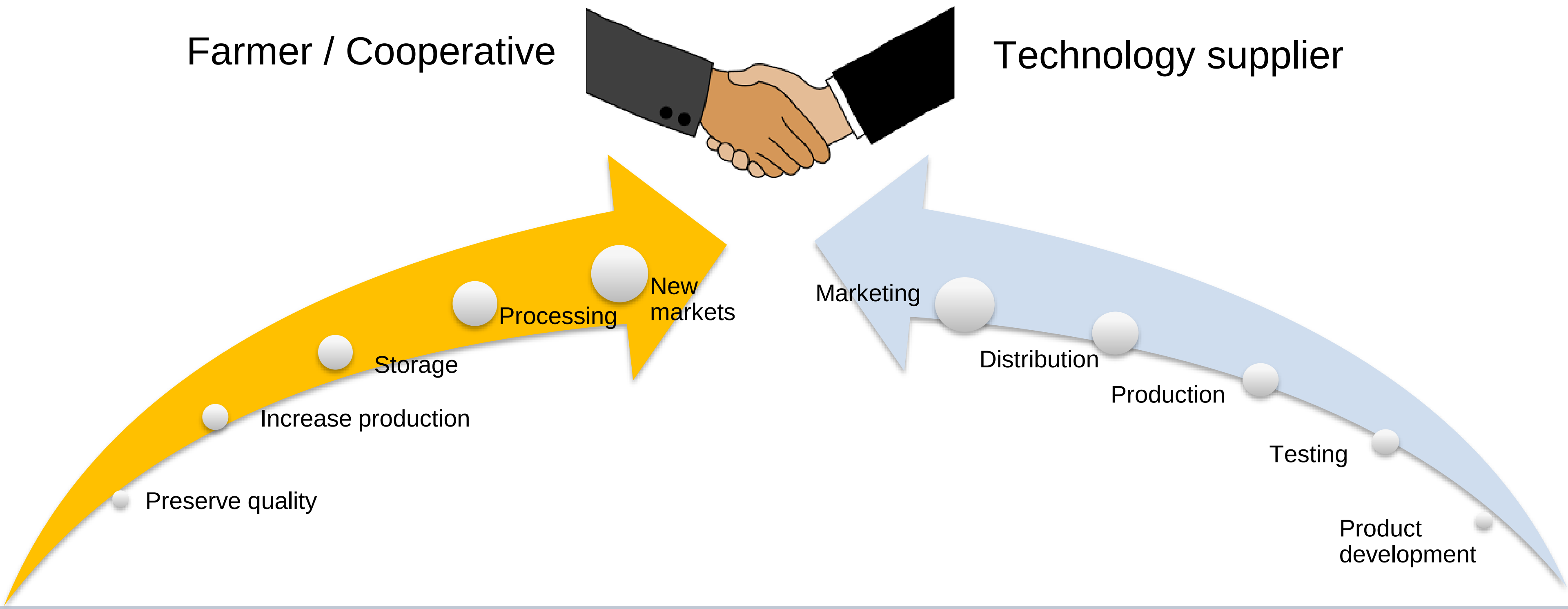
Solar cooling units +
Electronics and sensors +
Know-how



Locally produced
solar cooling systems



Business models



Challenges

- No quality based pricing
- Seasonal fluctuations
- Strong informal market
- Unreliable customers

- High transportation cost
- Lack of investments for R&D
- Expensive distribution and maintenance in rural areas

3 **Example** Systems

Example System 1:
Solar ice-maker

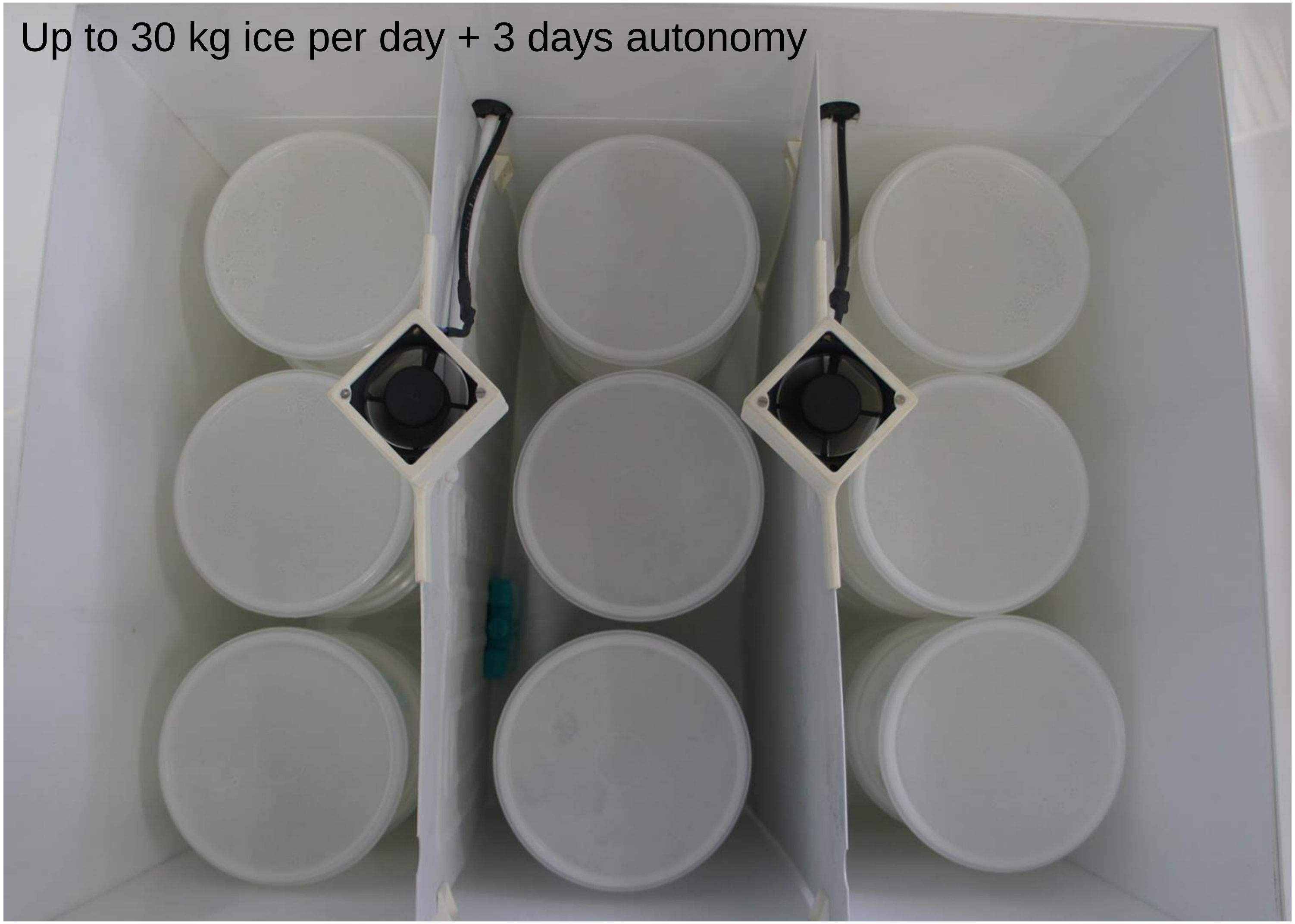
Example System 2:
Refrigerator battery-free

Example System 3:
Water Chiller for cold rooms
And water bath milk cooling

Solar ice-maker

Solar ice-maker

Solar ice-maker

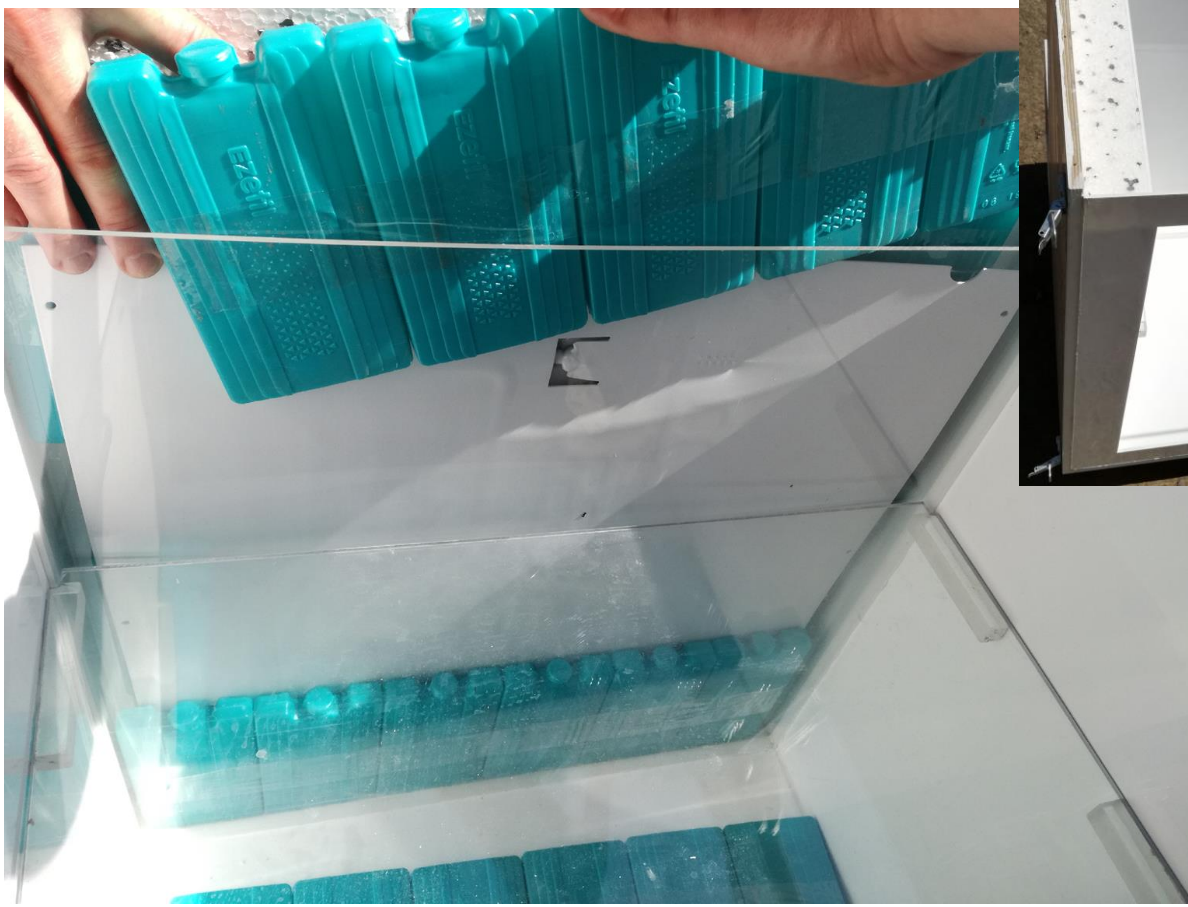


Solar milk cooling in insulated milk-cans with ice compartment

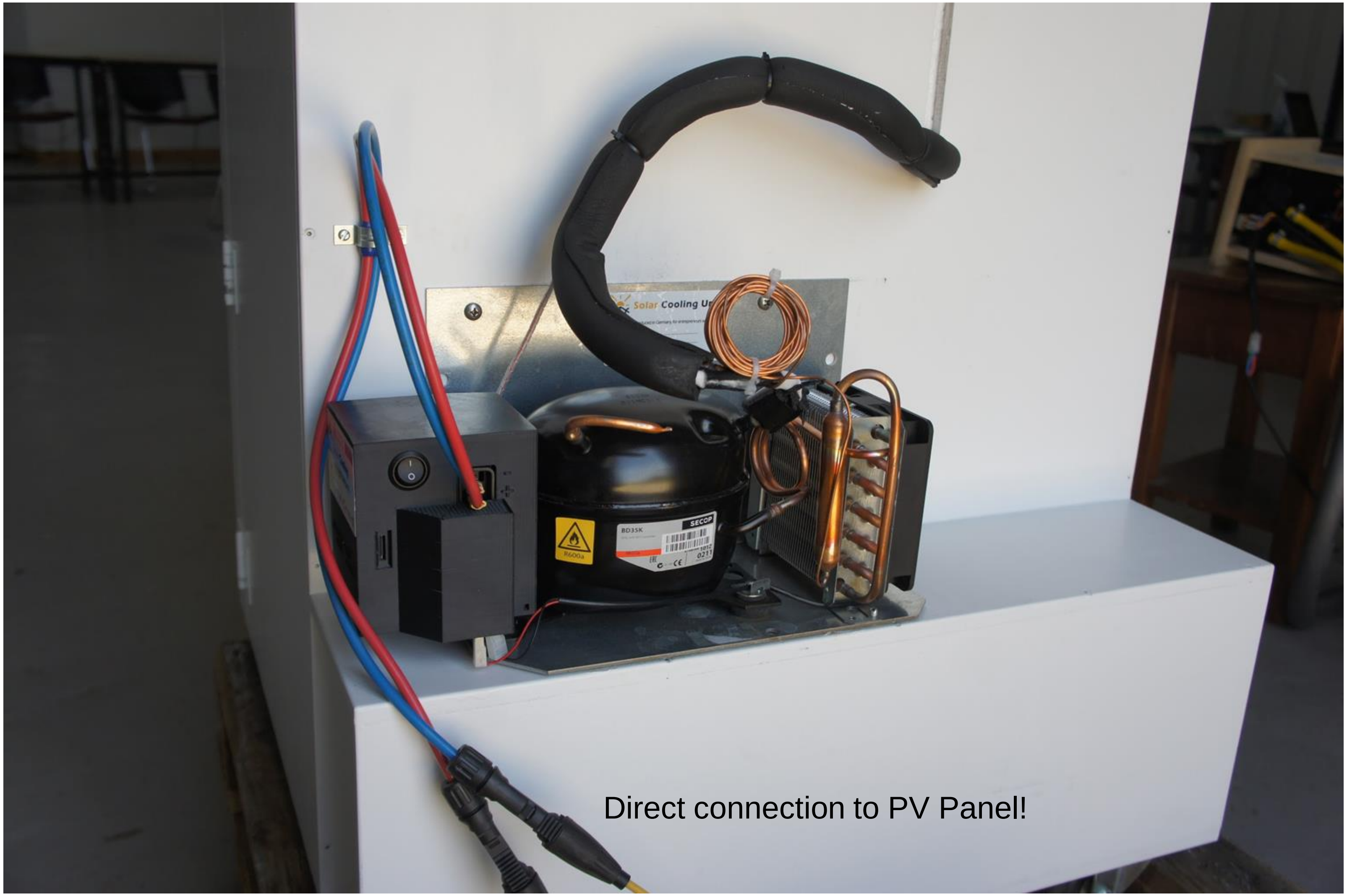
Cooling on-farm or during transport to collecting centers

Battery free refrigerator

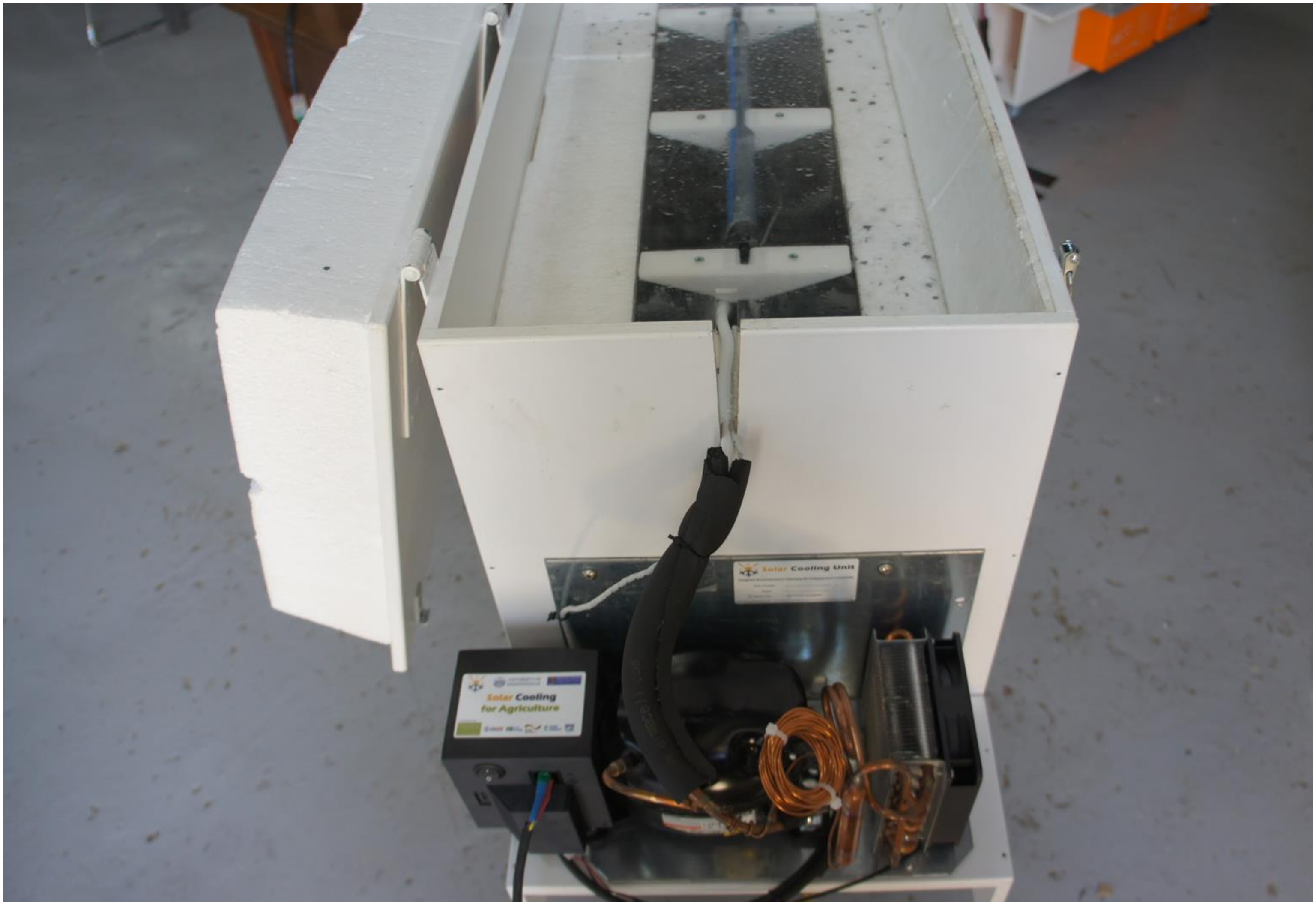
Battery free refrigerator



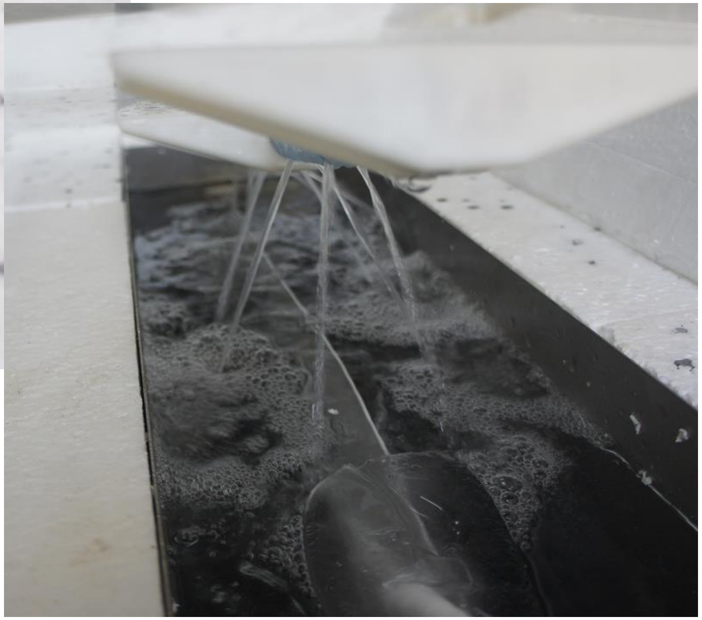
Battery free refrigerator



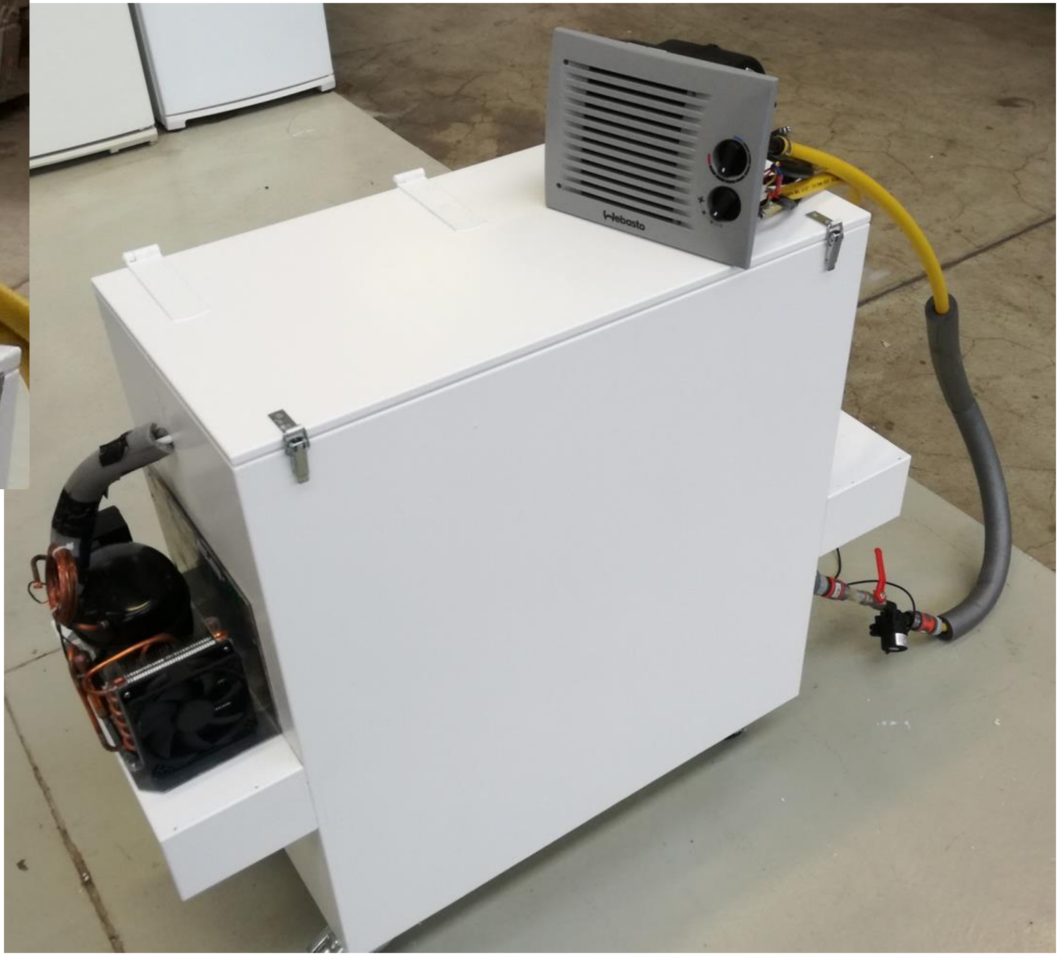
Water chiller



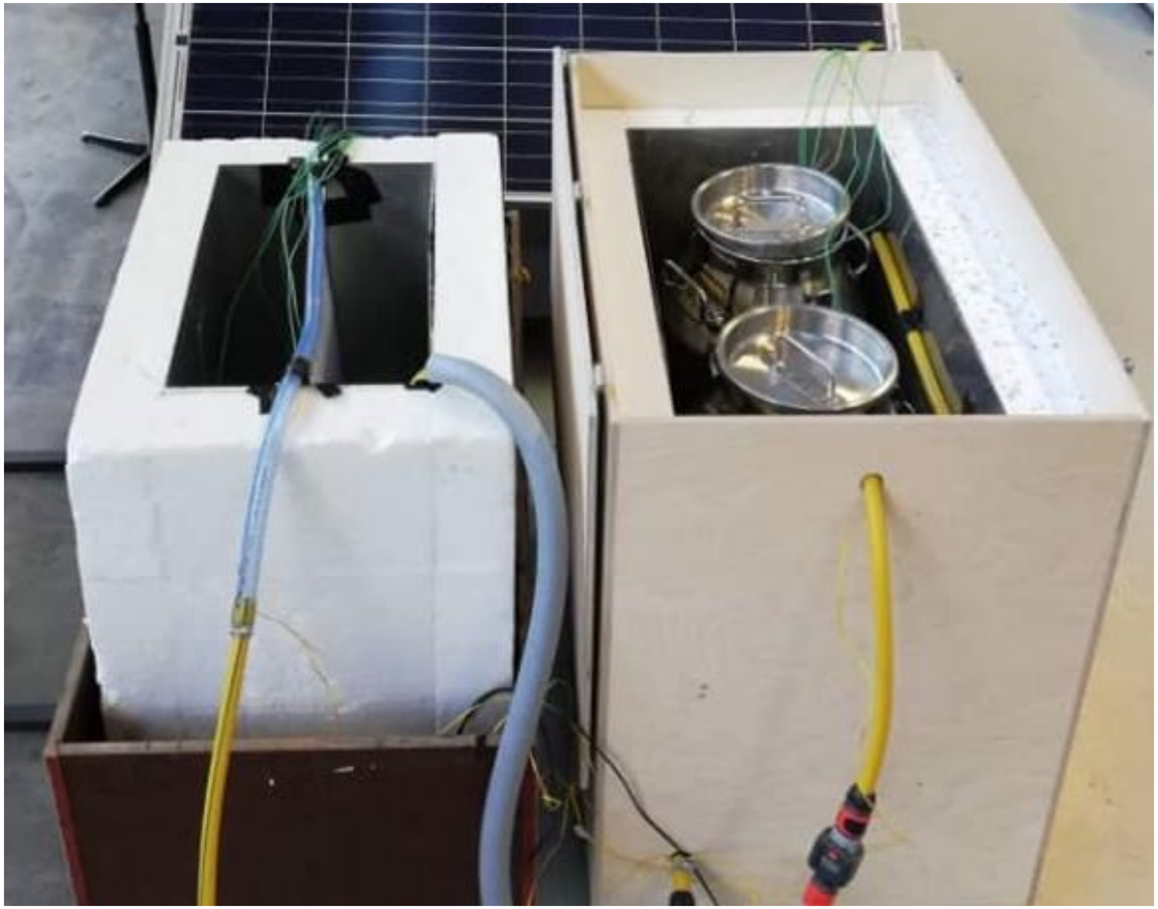
Water chiller

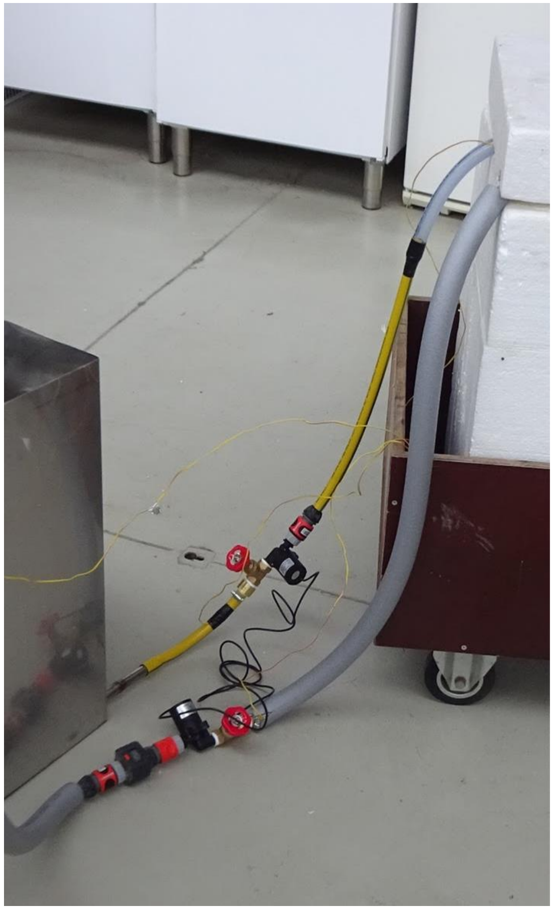


Water chiller for cold rooms



Water chiller + water bath for milk cooling





Scalability (Water Chiller)

1 Solar Cooling Unit

4 m³ cold rooms

or

80 L milk/day

12 Solar Cooling Units

20 feet container

or

1000 L milk tank

Importance of climate friendly refrigerants

NATURAL REFRIGERANTS

Source: http://naturalrefrigerants.info/

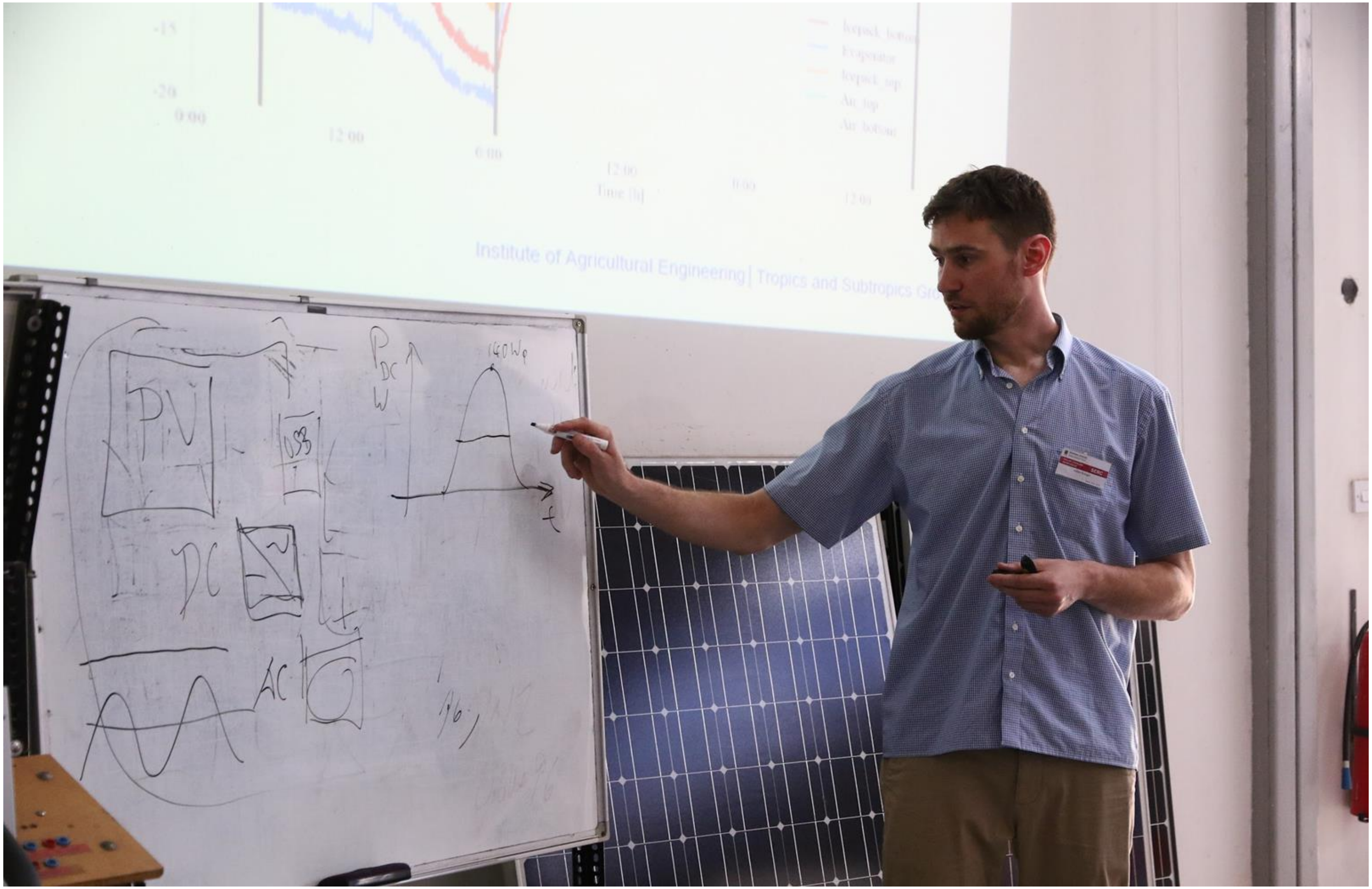
- R134a has Global Warming Potential (GWP) of 1400 kg CO_2 equivalent per kg
- Natural refrigerants as R290(Propane) or R600a(Isobutane) have GWP of around 3 kg CO_2 equivalent per kg.

Good to know!

The refrigerant of a typical solar refrigerator with R134a implies the Co_2 eq. emissions that are saved through the use of PV-Panels during almost 7 years!

Therefore, Solar always with natural refrigerants!

Training on Solar Cooling



Training on Solar Cooling

Training on Solar Cooling

Training on Solar Cooling

Training on Solar Cooling

Training on Solar Cooling

Training on Solar Cooling

Solar cooling manual

Manual

DIY Solar Cooling



UNIVERSITY OF HOHENHEIM

Assembly

5.2.2 Construction and assembly

Figure 23: Wooden box (u.l.), polystyrene insulation material (u.r.), ice packs for ice storage around the evaporator (d.l.) and the acryl glass plates for the internal covering

Figure 24: Gluing of the polystyrene insulation and internal acryl glass covering

5.3.2 Construction and assembly

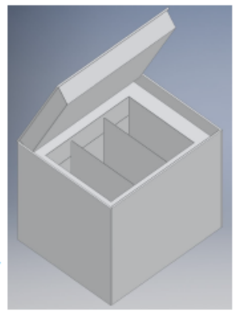
Figure 29: Wooden box (l.) and metal water container (r.) of the water chiller

Figure 30: Cut insulation material for the ice storage (l.) and the painted wooden box with the integrated insulation material and metal box (r.)

5 Construction and Performance

This chapter describes the process of designing, constructing and assembling of the example systems. Furthermore, a few results from performance tests are added.

5.1 Solar smart ice-maker

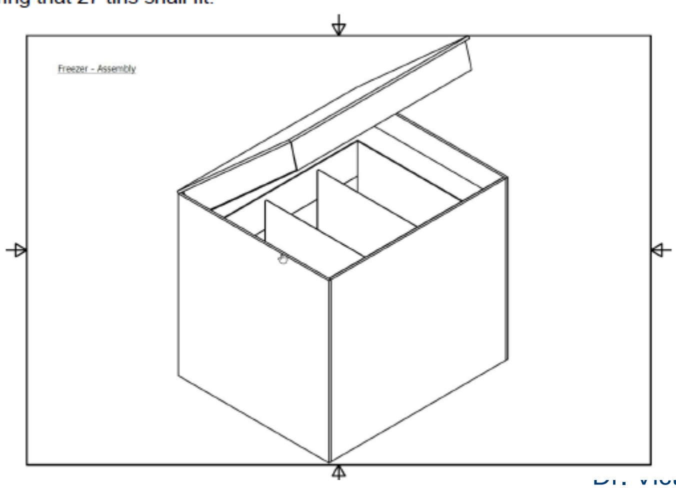


The goal for the Solar Smart Ice-Maker (SSIM) is to produce as much ice as possible, using energy from PV panels only. A battery together with a charge controller is connected to the Solar Cooling Unit (SCU).

The scope for the design and construction is only on the box itself and the assembly with the SCU.
For this design, the freezer compartment had to be big enough to store 27 plastic tins with 2 litres volume each. Two Solar Cooling Units are used in this setup.

5.1.1 Drawings

In the following, the CAD drawings are shown. The dimensions are derived from considering that 27 tins shall fit.



5.2.1 Drawings

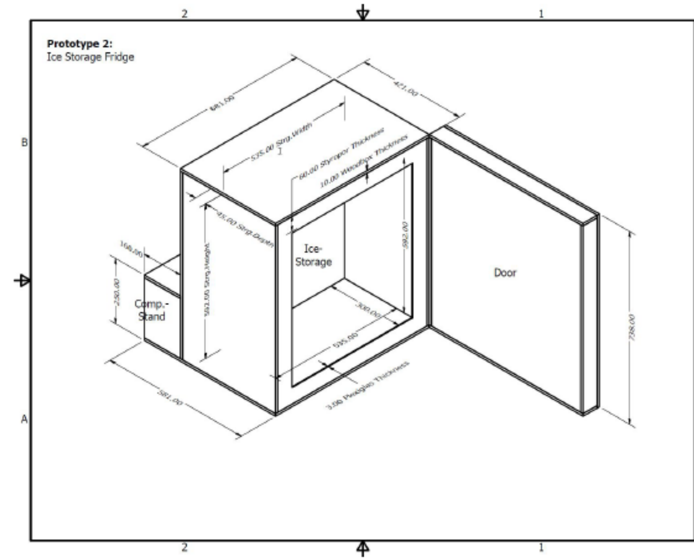
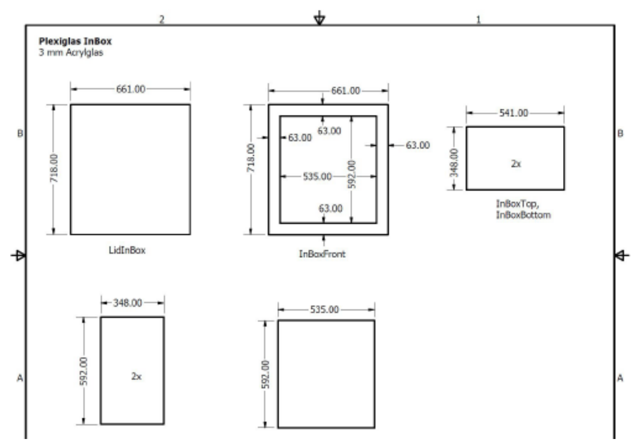


Figure 20: Drawing of the whole DDR with wooden box, insulation material and internal acryl glass cover

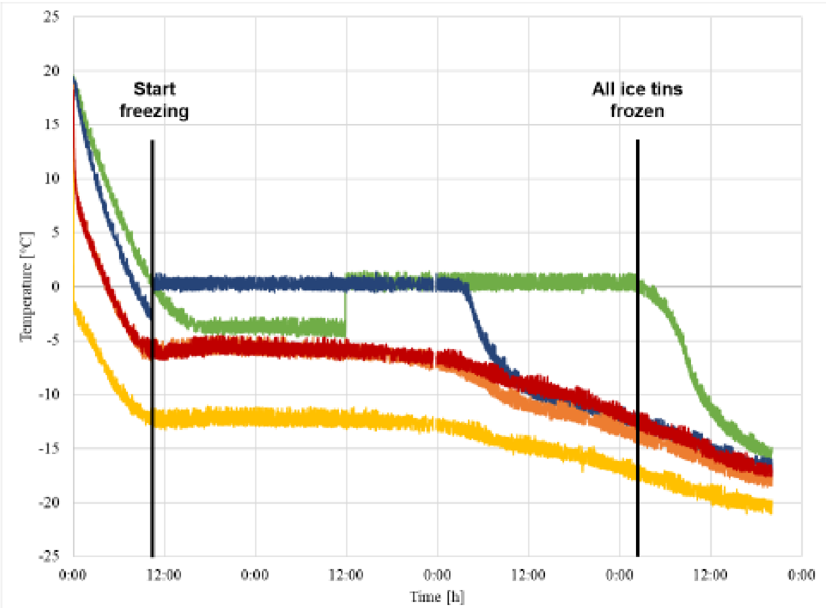


Performance

5.1.3 Performance

Table 1: Experimental setup for testing the performance of the SSIM

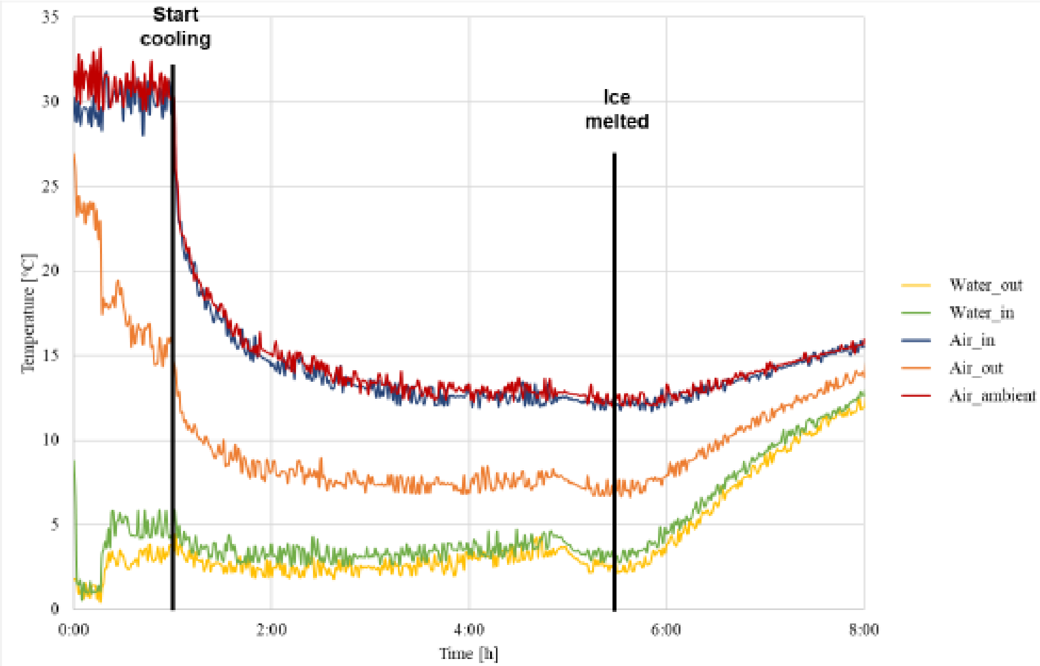
Ambient temperature:	30	°C
Water storage:	54 (27x2)	kg
Initial water temperature	18	°C
Freezing time	65	h
Total time	92	h



b) Discharge with cooling room application

Table 4: Experimental setup for testing the performance of cooling room application

Initial ambient temperature	30	°C
Ice mass	26	kg
Cooling time	4.5	h

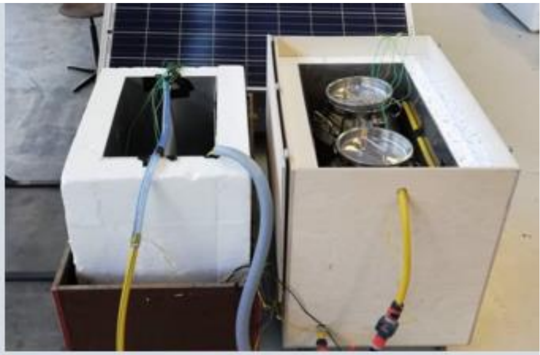


Solar Cooling Design Tool

1 Geographic Data

	January	February	March	April	May	June
Mean daily temperature [°C]:	25	26	26	26	25	23
Solar irradiation [kWh/m² day]:	6.2	6.6	6	5.3	4.6	4.3

Input of parameters



Select System: Water chiller for milk cooling

- Smart ice-maker
- Battery-free refrigerator
- Water chiller for milk cooling
- Water chiller for cold rooms
- Own system design

Product information | **set data**

Total mass to be cooled	Mass =	70	kg or l
Moisture content of the product	MC =	99	% wet based
or Heat capacity of the product	cp =	0	kJ/kg K

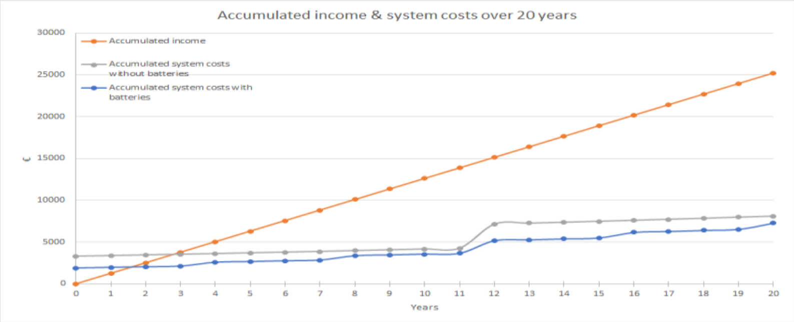
Temperature information

Initial temperature of the product	T_i =	35	°C
Final temperature of the product	T_m =	4	°C
Time to cool down the product	t =	4	h
How often do you cool down the product		30	per month

Solar Cooling Design Tool

Results

Selected System: Water chiller for milk cooling



System Design without batteries

Cooling units needed:	3	
Cooling units costs:	1950	€
Solar PV size:	819	Wp
Solar PV costs:	900.9	€
Total initial investment	**3301**	**€**
Payback period:	2.8	years
Net present value:	9,656	€
Internal rate of return:	35	%

System Design with batteries

Cooling units needed:	1	
Cooling units costs:	650	€
Solar PV size:	420	Wp
Solar PV costs:	462	€
Battery size:	168	Ah @12 V
Battery costs:	336	€
Total initial investment	**1898**	**€**
Payback period:	1.6	years
Net present value:	10,749	€
Internal rate of return:	60	%

UNIVERSITY OF HOHENHEIM

References

Projects

CGIAR. (2015). Field testing of an innovative solar powered milk cooling solution for the higher efficiency of the dairy subsector in Tunisia. Retrieved from https://mel.cgiar.org/projects/spmc

PARI. (2015). Program of Accompanying Research for Agricultural Innovation. Retrieved from http://research4agrinnovation.org/

GIZ-Powering Agriculture (2017) Assessment of business opportunities through the introduction of solar milk cooling in rural Colombia https://www.uni-hohenheim.de/organisation/projekt/assessment-of-business-opportunities-through-the-introduction-of-solar-milk-cooling-in-rural-colombia

GIZ- Powering Agriculture (2017) Piloting business models for solar milk cooling in Kenya https://www.uni-hohenheim.de/organisation/projekt/piloting-business-models-for-solar-milk-cooling-in-kenya

GIZ- Powering Agriculture (2018) Promotion of solar refrigeration for agricultural value-chains in Kenya https://www.uni-hohenheim.de/organisation/projekt/promotion-of-solar-refrigeration-for-agricultural-value-chains

Knowledge Management

energypedia: https://energypedia.info/wiki/Do_It_Yourself_-_Solar_Cooling_Units

https://energypedia.info/wiki/Solar_Milk_Cooling_with_Insulated_Milk_Cans

facebook: https://www.facebook.com/solarmilkcoolingteam/

YouTube: https://www.youtube.com/channel/UCeDM_4R0hrjWsj3EIKxYDrQ

Publications

On-farm milk cooling solution based on insulated cans with integrated ice compartment, International Journal of Refrigeration (2018), https://doi.org/10.1016/j.ijrefrig.2018.04.001

Design and performance of a small-scale solar ice-maker based on a DC-freezer and an adaptive control unit, Solar Energy (2016), https://doi.org/10.1016/j.solener.2016.10.022

Performance characterisation of a small milk cooling system with ice storage for PV applications, International Journal of Refrigeration (2015), https://doi.org/10.1016/j.ijrefrig.2015.06.025

Capacity Building and engineering services

http://solar-cooling-engineering.com

Acknowledgments

POWERING AGRICULTURE: AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

german cooperation DEUTSCHE ZUSAMMENARBEIT

Federal Ministry for Economic Cooperation and Development

USAID FROM THE AMERICAN PEOPLE

Sweden Sverige

DUKE ENERGY

OPIC

EFFICIENCY FOR ACCESS

clasp

energy saving trust

UKaid from the Department for International Development

PARI

zef Center for Development Research University of Bonn

BBV-Landfrauen Internationale Zusammenarbeit GmbH

ICARDA Science for Better Livelihoods in Dry Areas

INRAT

ITAACC Project

giz

Thank you for your attention!

Merci beaucoup pour votre attention!