UNIVERSITY OF HOHENHEIM

Manual

DIY Solar Cooling

Solar Cooling Team within the Tropics and Subtropics Department (440e)

Institute of Agricultural Engineering, University of Hohenheim, Germany

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In cooperation with:

POWERING AGRICULTURE: AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

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1 Background

The University of Hohenheim has been carrying out research on solar cooling for the last 5 years. A smart solar ice-maker has been developed and applied for milk cooling. Up to now, 18 Systems have been successfully assessed together with local partners in Tunisia, Kenya and Colombia showing its technical feasibility. Since 2017, the economic feasibility is under study in cooperation with partners of the private sector and in synergy to several ongoing public initiatives.

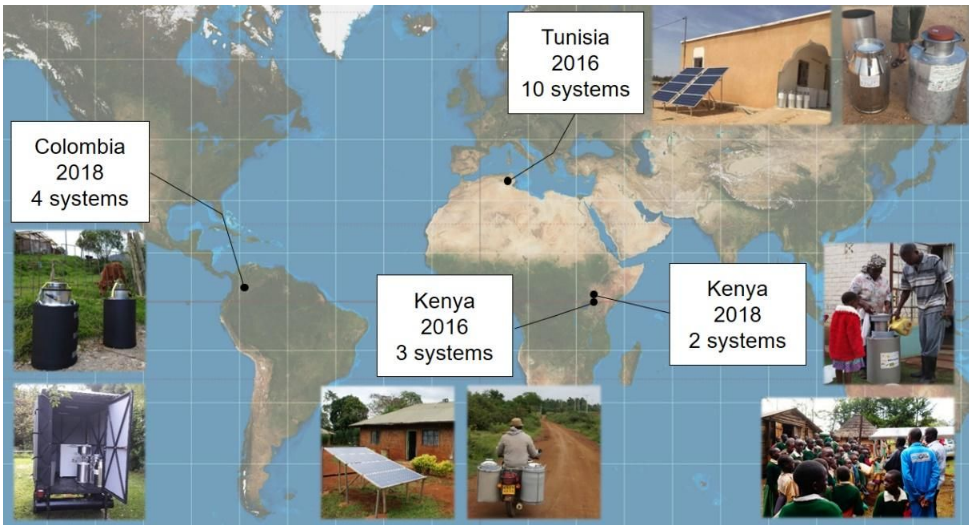


Figure 1: Hohenheim solar milk cooling projects

Based on the outputs of the last projects, the University of Hohenheim currently supports the use of "cooling units" instead of "cooling systems" as strategy to reduce the final price of the technology while creating specialized jobs locally.

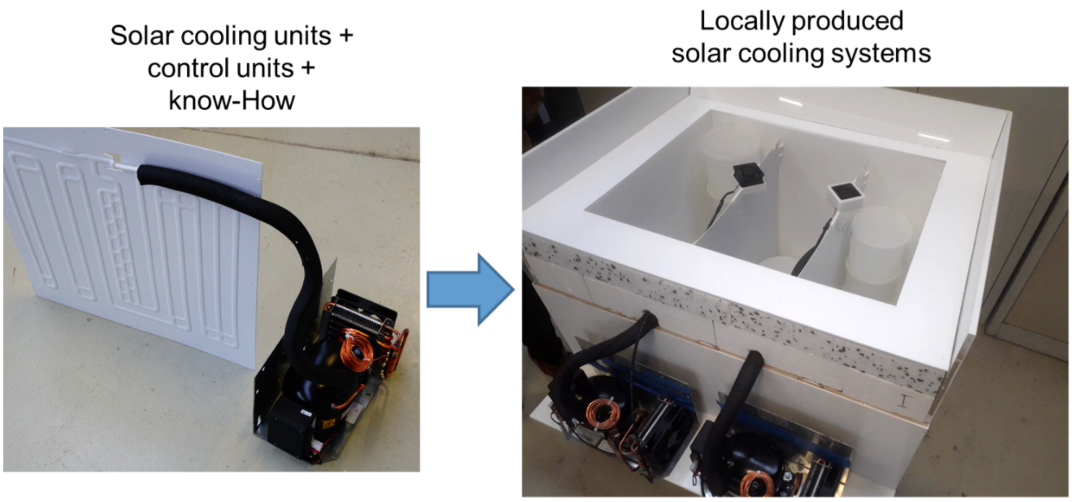


Figure 2: Hand produced smart ice-maker based on the use of "cooling units"

By following this strategy, high-tech components as the cooling units and electronics, can be exported while the assembling of the insulation-box can be carried out locally. This way, entrepreneurs have the possibility to adapt the technology to the local market and offer distribution and maintenance under their own product brand.

Project references

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 Development and Engineering Services

http://solar-cooling-engineering.com

2 Market potential of locally produced solar cooling systems

About 1.28 billion people worldwide still lack access to electricity, and another one billion people have access only to an unreliable grid. More than two-thirds of the population of Sub-Saharan Africa—620 million people—lack access. Diverse interventions, ranging from national rural electrification plans to multilateral initiatives, are playing an important role in reducing market barriers to delivering clean energy to off-grid communities. Actual mainstream Refrigerators is after TVs and Fans, the most demanded Appliance with an estimated current spending of USD $75 million by off- and bad-grid households. Estimated annual spending on off-grid refrigeration products in 2020 could reach USD $1.1 billion. While market for refrigerators in industrialized countries is saturated and presents limited opportunity for growth, the penetration of refrigerators in non-industrialized countries, specifically in rural areas, remains extremely low. Studies indicate that, historically, the penetration of refrigerators starts to take off at an average annual per capita income of USD $2,500. Developing low-cost, high-quality, energy-efficient refrigerators customized for rural, off-grid markets can contribute to the increased uptake of solar cooling systems in rural areas for households or agricultural value chains.
Overall, off-grid refrigeration products require additional research and development on technology and design to unlock their commercial potential. The demand for refrigerators will be driven in part by their potential contribution to income-generating activities. Nevertheless, Key barriers on price need to be addressed in order for refrigerators to be viable for off-grid communities[1].

The University of Hohenheim has developed an approach where both value chains of final users and technology supplier is considered. Recent research in the field has shown that e.g. farmers face several challenges to profit from business opportunities related to the access to cooling systems. Those are related on how those cooling systems adapt to the reality of the given food value chain. From the other side, the business model of future technology suppliers faces the challenges of expensive transport/import cost of those system added to the distribution and marketing cost related to the introduction of products in isolated rural areas. Therefore, the promotion of solar cooling systems needs to consider the fact that, technical solutions can only become economically sustainable if are being designed, produced, installed and be on maintenance by local skilled staff in close collaboration with final users, e.g. farmers.

Challenge	Strategy
Cooling systems adapted to value chain	Design by local skilled staff
High cost of imported cooling systems	Reduction of transport cost by using solar cooling units + local assembling
Expensive distribution and Maintenance in rural areas	Manufacturers are located in rural areas
Unreliable business models for farmers	Introduction of cooling systems including several stakeholders of the value chain + Pay as you go finance

[1] 2015 Global Leap report "The State of the Global Off-Grid Appliance Market"

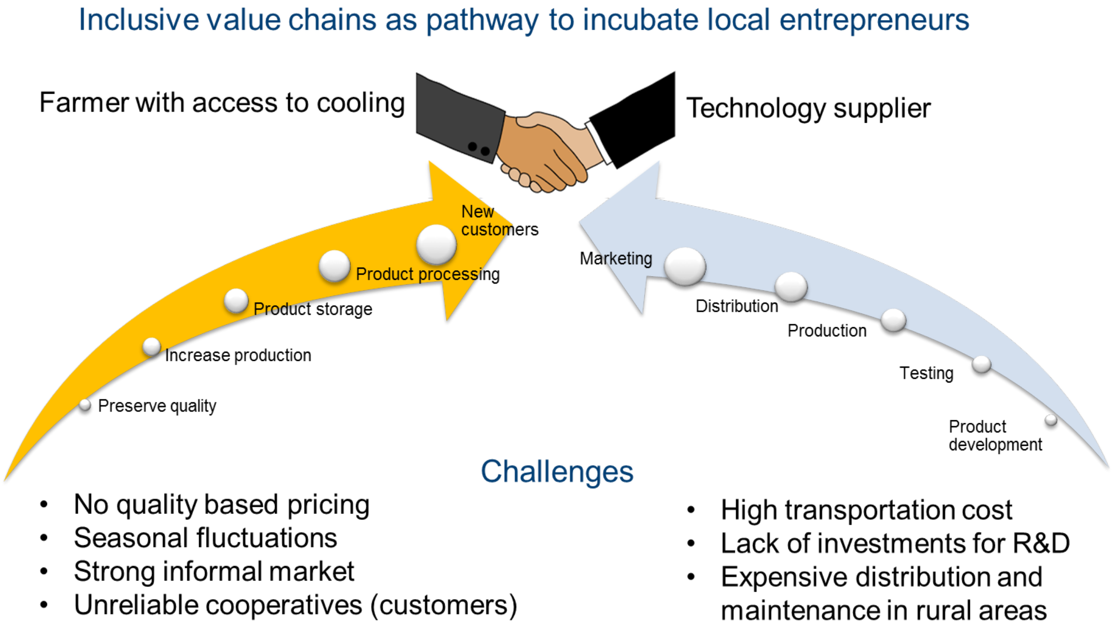


Figure 3: Inclusive value-chain approach followed by the University of Hohenheim

By promoting the use of solar cooling units (compatible to different systems configurations), transport cost is reduced by 75% in comparison to imported refrigerators. 10 Cooling units (ready for Plug&Play) can be transported in one EUR Pallet of dimensions (L x B x H):1400 x 800 x 1200 mm. Aprox. 100kg total weight. Entrepreneurs or local companies can freely design and produced final products under their own brand, which increase the perspectives of economic growth. The business model not only rely on the cost reduction but also on the competitive advantage of being able to adapt and scale different products tailor to final user needs.

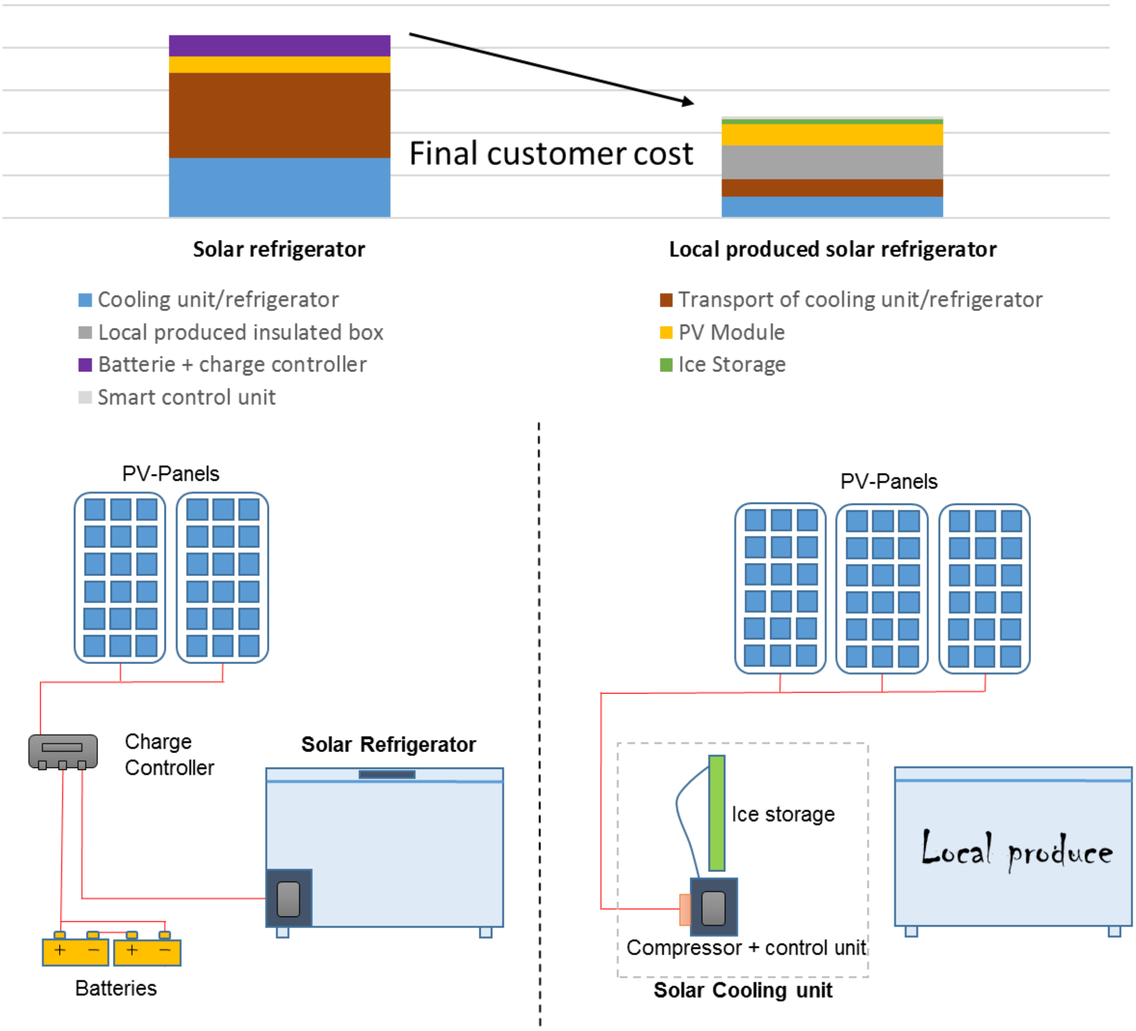
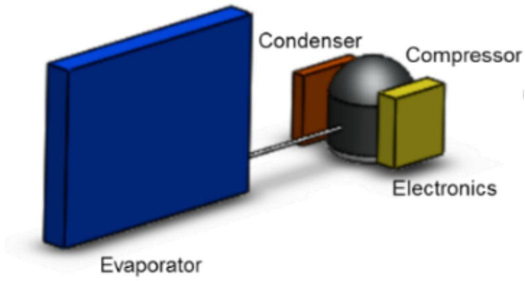


Figure 4: Cost reduction expected for local produced solar cooling systems (Example for a solar refrigerator)

3 Solar cooling unit

The Solar Cooling Unit is a hermetically sealed cooling device that works as a vapor-compression refrigeration machine. It is ready to be plugged to photovoltaic systems for different cooling applications.

The Unit consists of the following parts: Compressor, Condenser, Evaporator plate, temperature sensors and control unit.



Parts:

Compressor:	SECOP BD35K
Electronic Unit:	101N0420
Condenser, evaporator Plate, capillary tube. Filled with refrigerant.	
Electronic control unit, temperature sensors and PV Connection. Plug & Play	
Optional: Programer to customize operation strategy (Software)	

Performance:

Power consumption	75 W
COP	Between 1.5 – 2.5 2.0 producing ice at an ambient Temperature of 35°C
Temperature Range	Evaporator: -20°C to 5°C Ambient: 10°C to 45°C
Voltage Range	10-45 V DC
Refrigerant	R-600a (Isobutane), 45g
Dimensions (packed):	250 x 600 x 630 mm (Width, Length, Height)
Weight (packed):	10 kg

Main features:

a) Cooling engines specially designed for a plug and play local assembly
b) Compatibility with battery free solar systems by integrating phase change materials
c) Usage of climate-friendly natural refrigerants
d) PAYGO compatibility

4 Example systems

In the frame of a current on-going project funded by Powering Agriculture(GIZ), the University of Hohenheim has developed 3 example systems for different cooling applications. Those example systems, which can be produced locally, are used for capacity building purposes with the aim of training promising entrepreneurs/companies for common future field testing interventions.

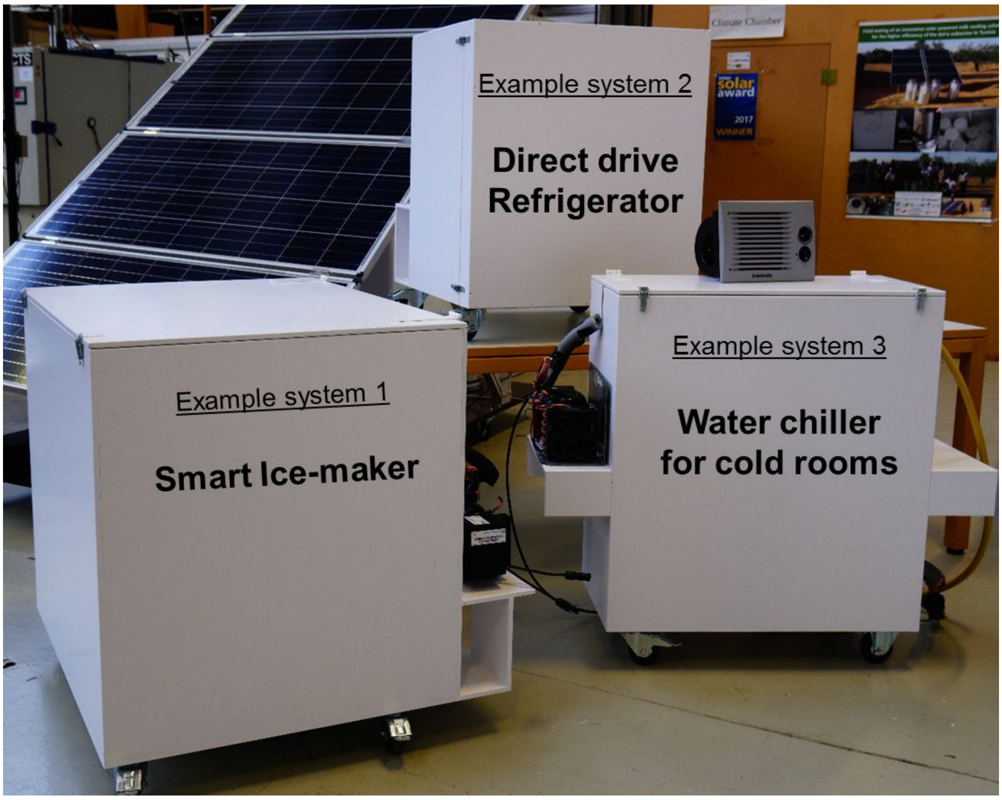


Figure 5: Overview of the 3 solar cooling example systems developed by the University of Hohenheim

4.1 Example System 1

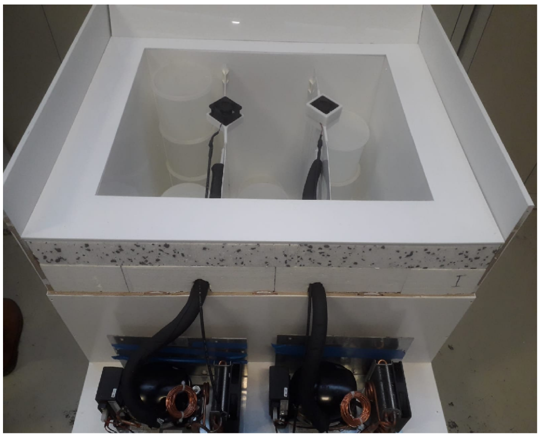
Solar ice-maker

Target applications:

- Ice based fish cooling
- Milk cooling in insulated milk-cans

Performance at 30°C ambient:
12 kg ice per day and cooling unit

Solar components needed:
PV Panels(200Wp) + Battery (40Ah@12V)



4.2 Example System 2

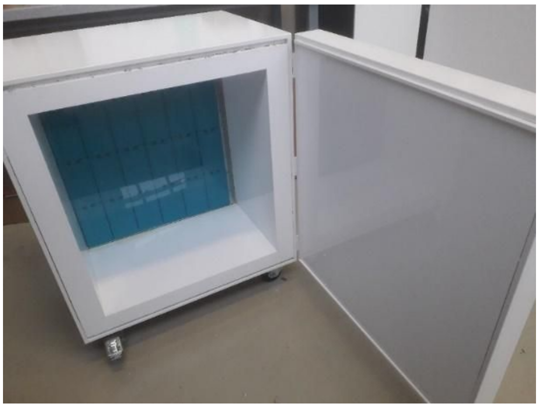
Direct drive refrigerator (Battery free)

Target applications:

- Refrigeration of food
- Household refrigerator

Performance at 30°C ambient:
4-8°C inner temperature. Autonomy of 24 h

Solar components needed:
PV Panels(150Wp)



4.3 Example System 3

Water chiller (Ice storage system)

Target applications:

- Refrigeration of food in cold rooms
- Milk cooling in cold water bath
- Fish cooling in cold water bath
- Air conditioning

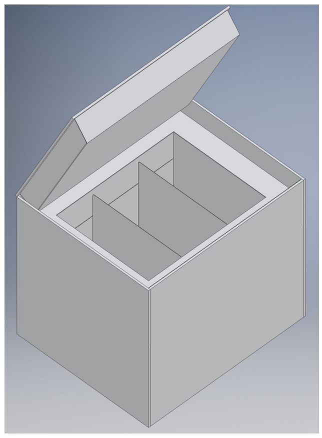
Performance at 30°C ambient:
Water temperature 4°C
3000 kWh thermal storage
800 W max thermal power
Minimal cooling room temperature 10°C

Solar components needed:
PV Panels(200Wp) + Battery (40Ah@12V)

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.

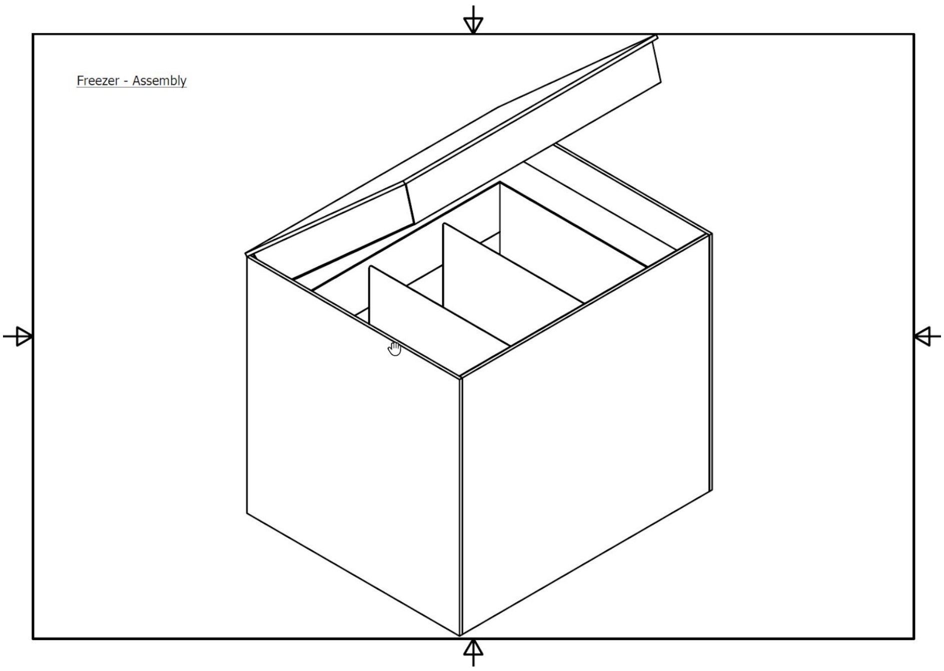


Figure 6: Drawing of the complete smart solar ice maker with the wooden box, insulation, Acryl glass and the evaporator plates

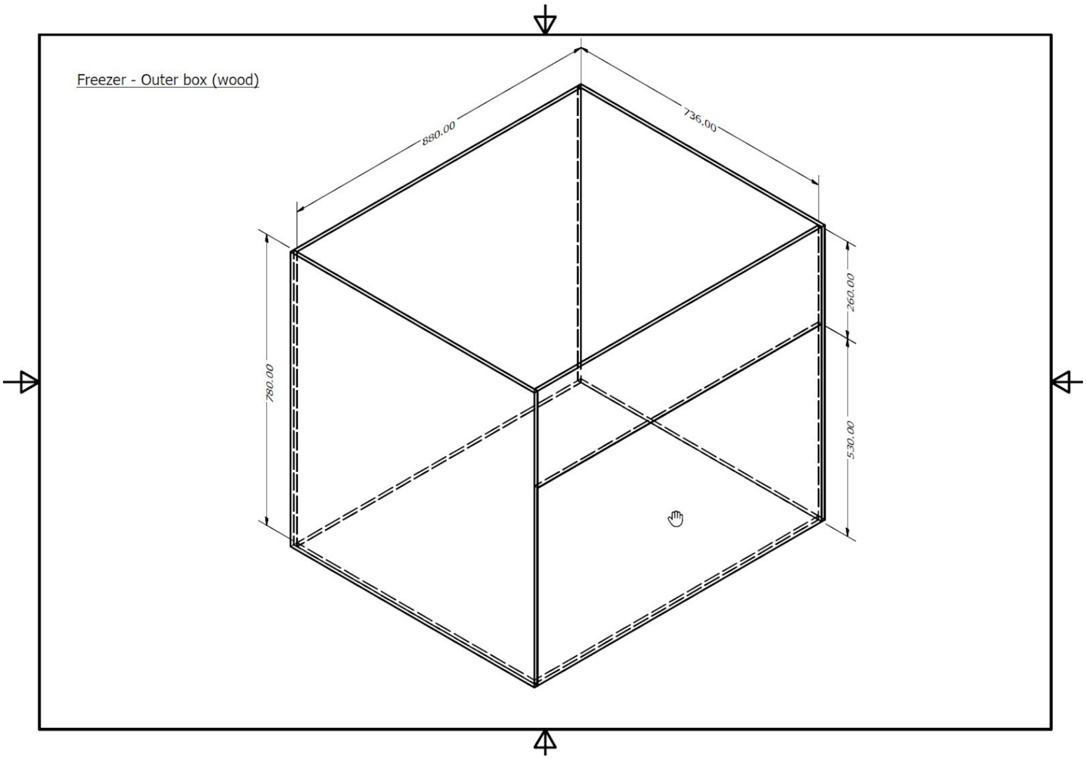


Figure 7: Drawing of the wooden outer box of the SSIM

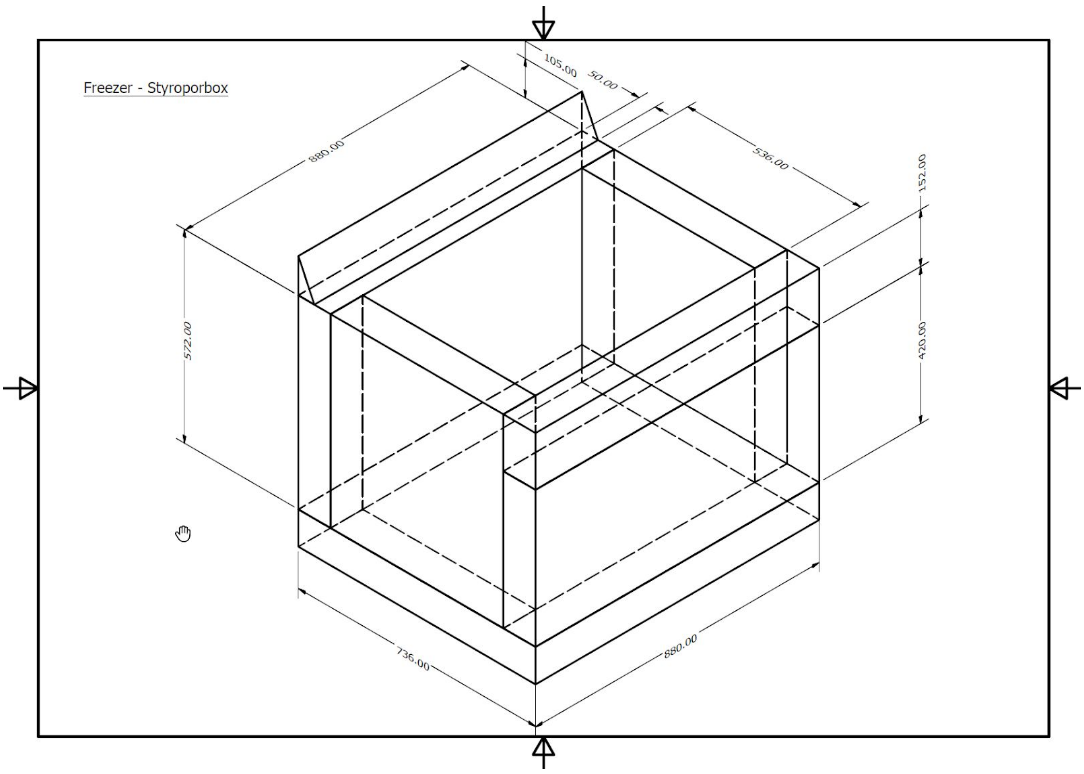


Figure 8: Drawing of the polystyrene insulation material of the SSIM

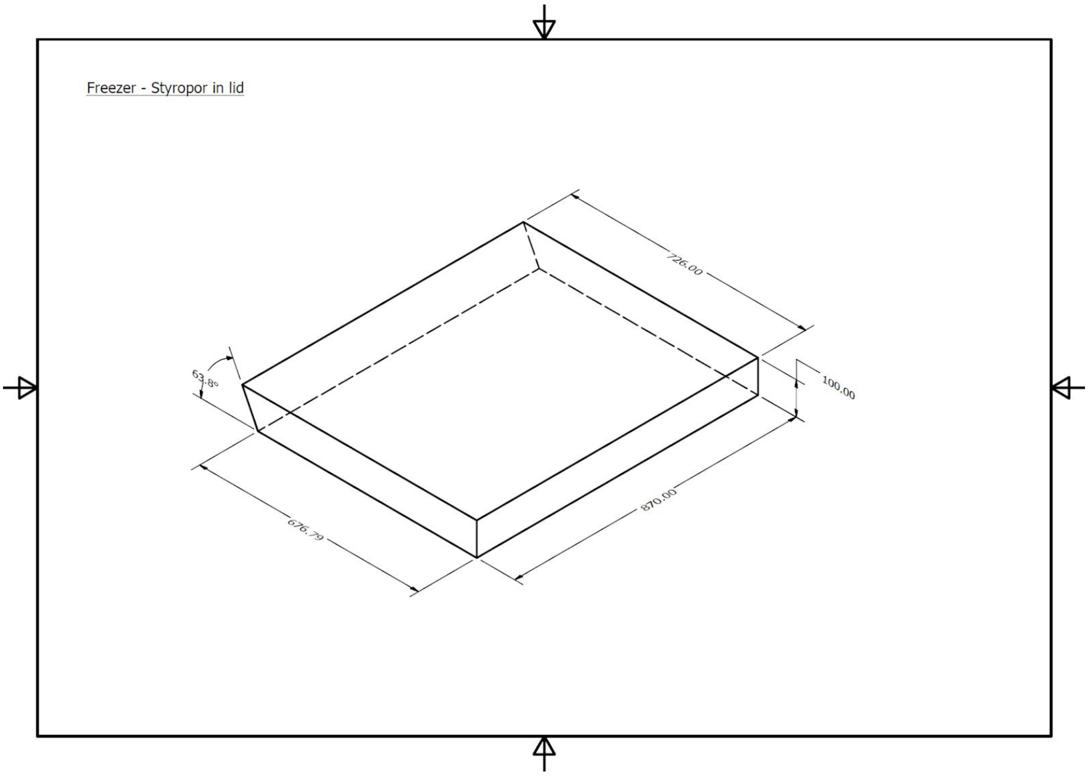


Figure 9: Drawing of the polystyrene lid of the SSIM

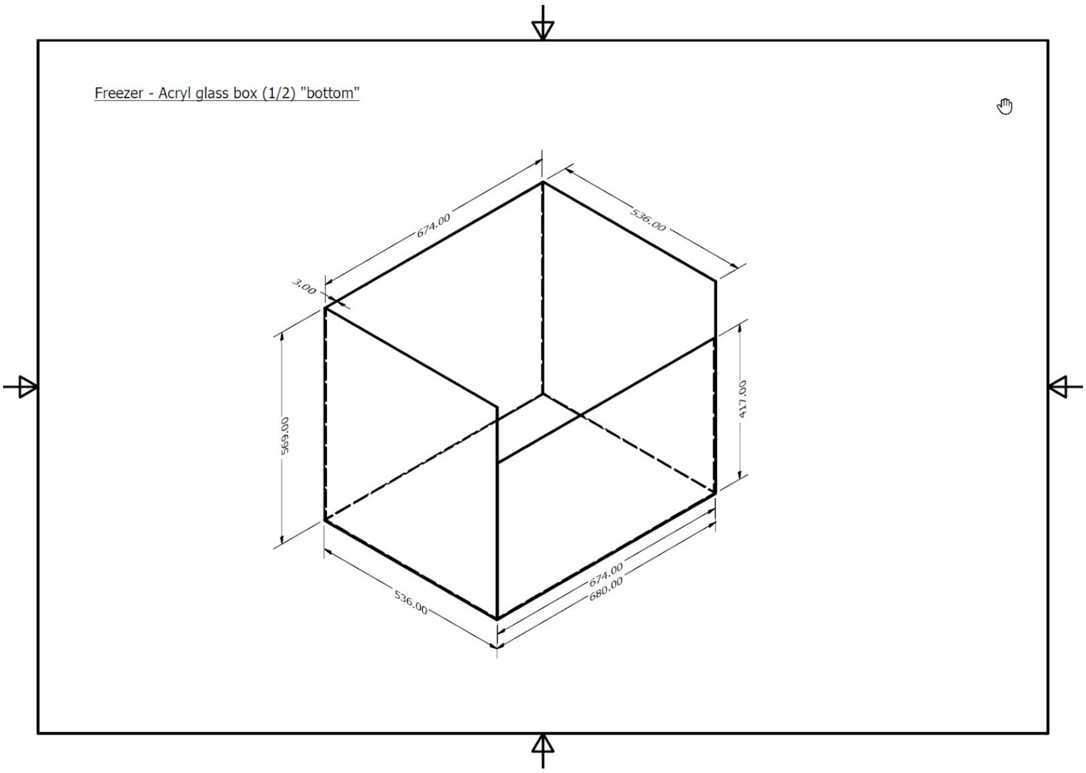


Figure 10: Drawing of the acryl glass for the inner covering

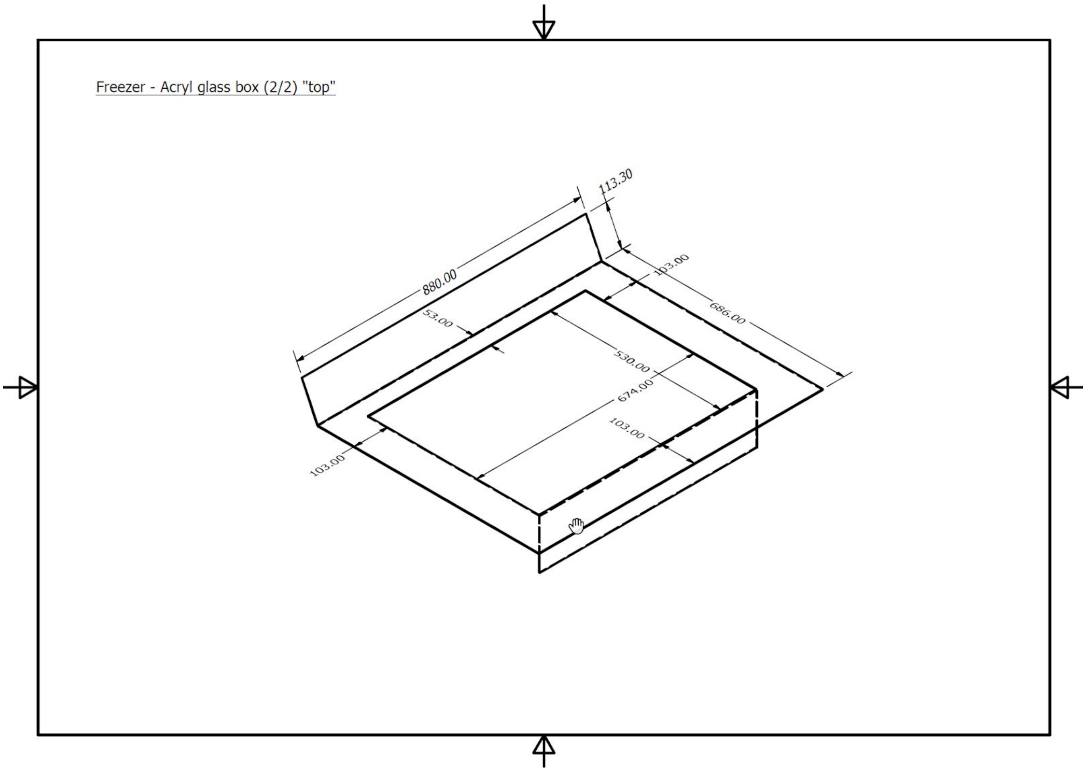


Figure 11: Drawing of the top acryl glass covering

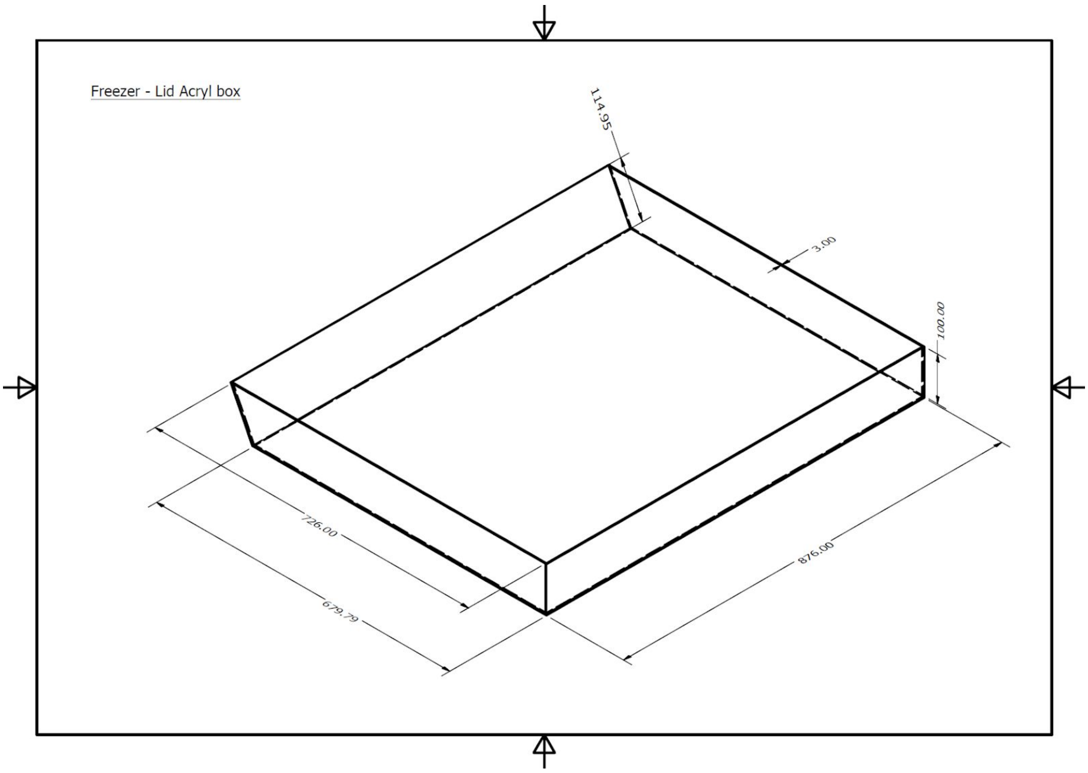


Figure 12: Drawing of the acryl glass covering of the insulation on the lid

5.1.2 Construction and assembly

The SSIM consists of two main parts:

1. a hinged lid, that opens up on top of the freezer (“chest freezer”),
2. the main body.

To allow the assembly of the cooling units, the main body part has a removable part at the back wall.

The construction has three main layers:

1. an outer box: cut from 12mm plywood sheets, painted with white waterproof varnish
2. insulation material: 100mm thick polysterene sheets
3. inner layer: acrylic glass, 3mm thick
   Remarks:
   - the surface of the inner box is only made out of acrylic glass
   - there is a hole to allow removal of water from within the inner box, which is closed by a removable plug during operation
   - all of the insulation is covered by acrylic glass

The dimensions of these layers are determined starting from the inner box: adding the thickness of the acrylic glass, the dimensions of the insulation layer is determined. Again, considering the thickness of the insulation, the dimensions of the outer box is found.

Cutting optimisation:
For having a minimum of material loss, a software tool is used for cut optimisation.
For example: Free Online Panel (2D) Cut Optimizer from Optimalon Software Ltd. (http://www.optimalon.com/online_cut_optimizer.htm)

The assembly starts with the construction of the outer box. In our example, we also attach 4 rubber wheels under the bottom, to be able to move the SSIM easily. Furthermore, a holder plate is added at the back where two SCUs, a charge controller and a battery can easily be placed.

The Lid part of the box, together with the upper back part of the box are not assembled yet, to later allow the installation of the SCUs.

Then the Insulation layer is added for the main body. Again, the upper back part is not assembled yet, as can be see in the next figure:

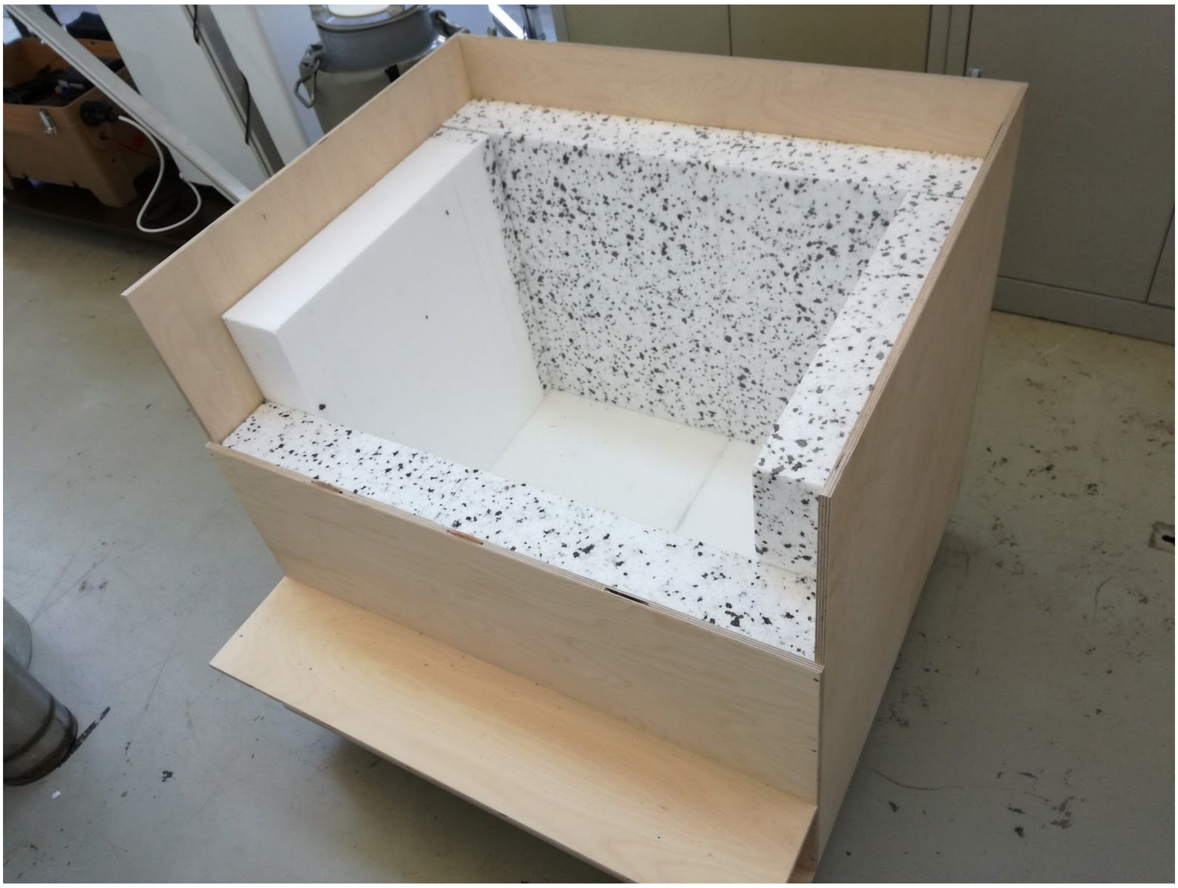


Figure 13: Insulation material placed inside the wooden box

The next step is to assemble the inner box. We recommend two options to glue the inner box parts together:

1. use a silicone glue pistol to make a waterproof connection. The sheets can be put in place inside the box together with the insulation, so that the final position can be fixed with the silicone glue. Make a clean line of glue through all corners so that a water-proof connection is created.
   <u>Or:</u>
2. use acryl glue. Please pay attention to usage and safety instructions for acryl glue, as it can be very harmful. The assembly and <u>gluing may not happen inside the box with the insulation material</u>! The glue damages the polysterene and therefore has to happen in a different space. Take care, that the shape of the inner box remains as designed, as it still needs to be fitted inside of the outer box.

As a next step, the two SCUs can be assembled:

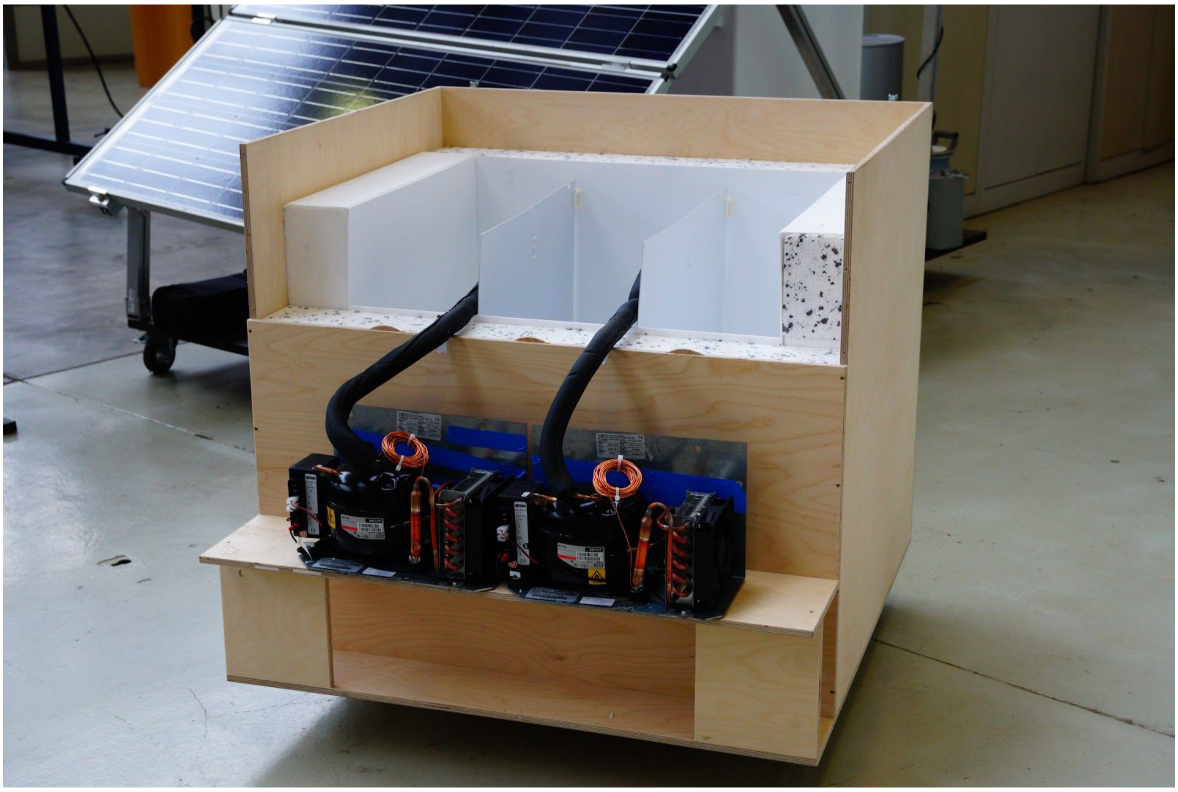


Figure 14: Two cooling units placed into the SSIM

In our design, we place the SCUs so that the evaporator plates separate three equally big compartments. Here, each one is big enough to comfortably place plastic tins for ice generation.

To make room for the tubes and cables of the SCUs, now the upper back part of the insulation material, the outter box, and the acrylic glass must be marked and cut to a U-shaped recess. These parts can be assembled in the next step. For cutting the insulation material, a simple hot-wire cutter is the best choice:

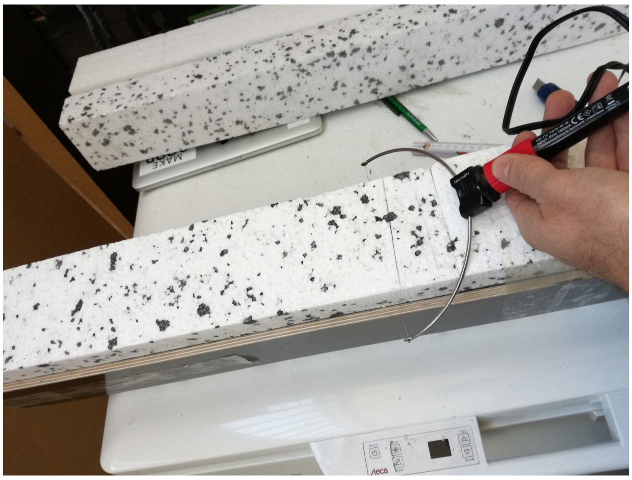


Figure 15: Cutting polystyrene material with a hot wire cutter allows manual cutting

In the next step, the top of the inner box will be assembled, so that no insulation is visible anymore (only on the upper back part):

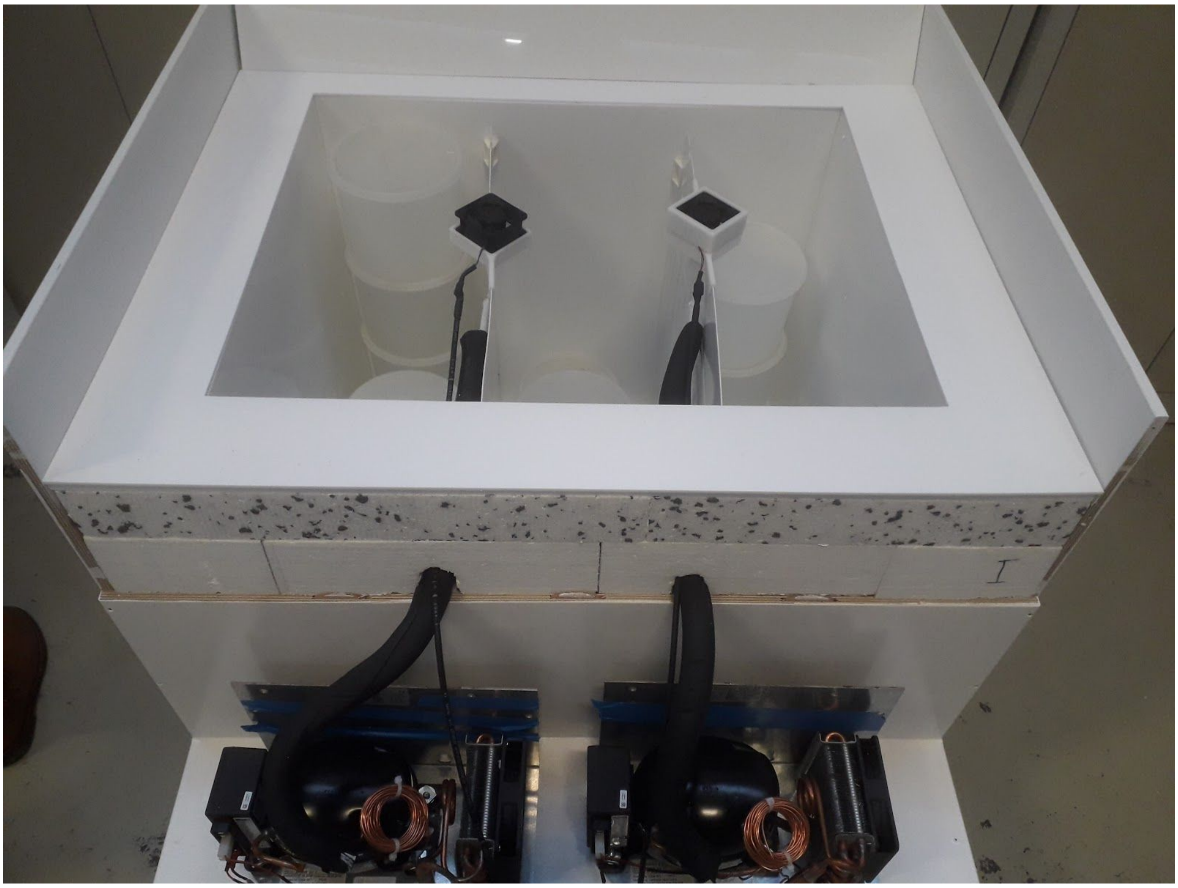


Figure 16: Complete covered and painted SSIM with fans and water filled ice tins (without lid)

Following steps:

- assemble lid: hinge at the back, lock at the front
- glue the plate holders (final position)
- assemble fan holder on evaporator plates, attach sensor and fan cables
- finalise front corner insulation and cover plate
- all: use silicone glue or other
- paint with varnish

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

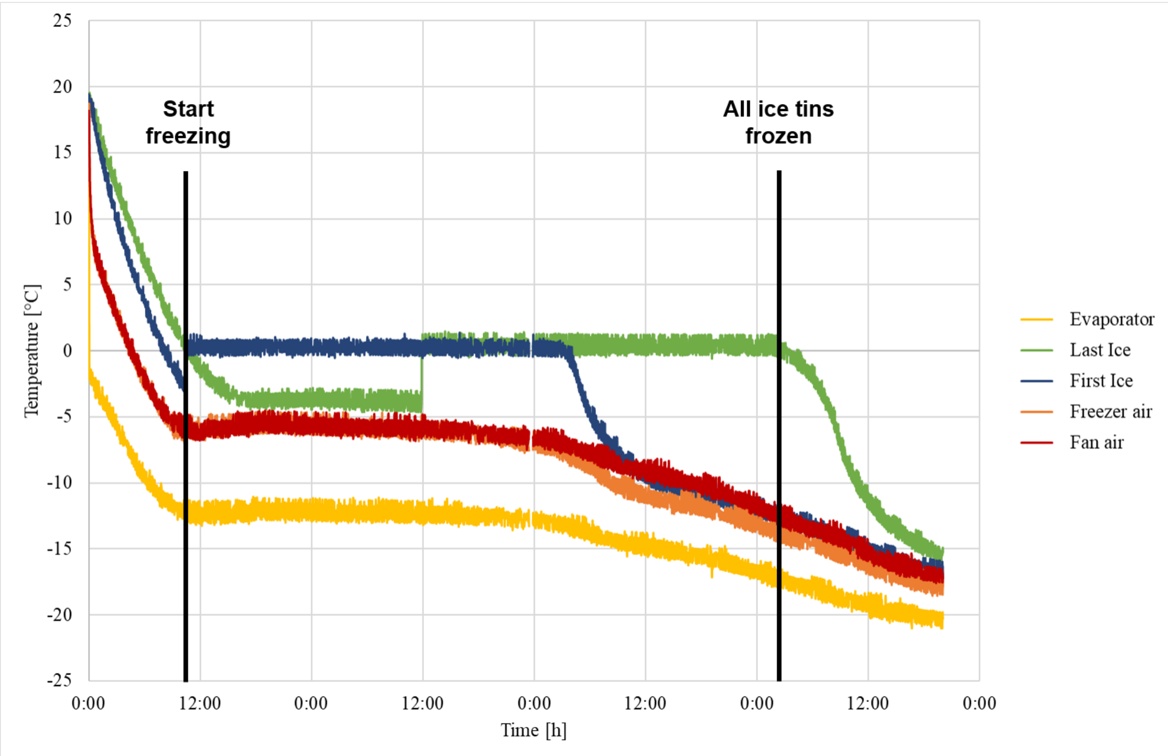


Figure 17: Graph of a cooling performance experiment with 54 kg water in the SSIM. "First Ice" and "Last Ice" are the temperature curves for the tins that started as the first and the last one, respectively. "Freezer air" is the air temperature inside the freezer chamber and "Fan air" the temperature of the air at the outflow of the fan.

5.2 Direct drive refrigerator

Figure 18: Painted wooden box of the direct drive refrigerator (DDR)

Figure 19: DDR with ice packs in the back wall around the evaporator

5.2.1 Drawings

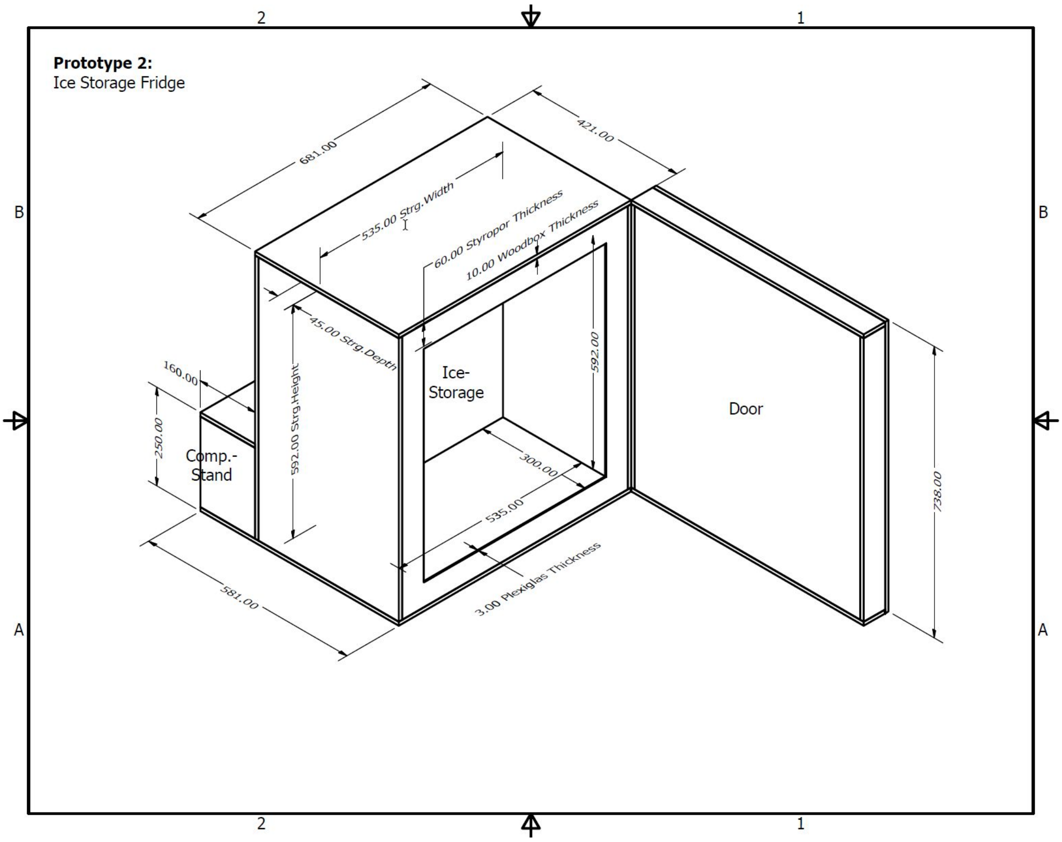


Figure 20: Drawing of the whole DDR with wooden box, insulation material and internal acryl glass cover

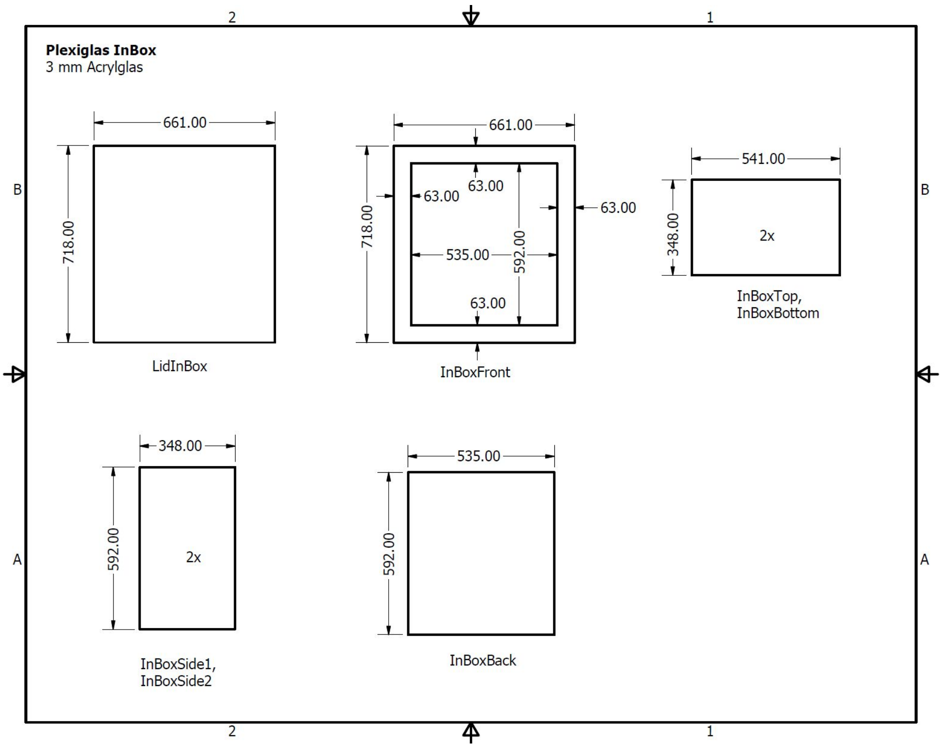


Figure 21: Drawings of all acryl glass plates for internal coverage for the DDR

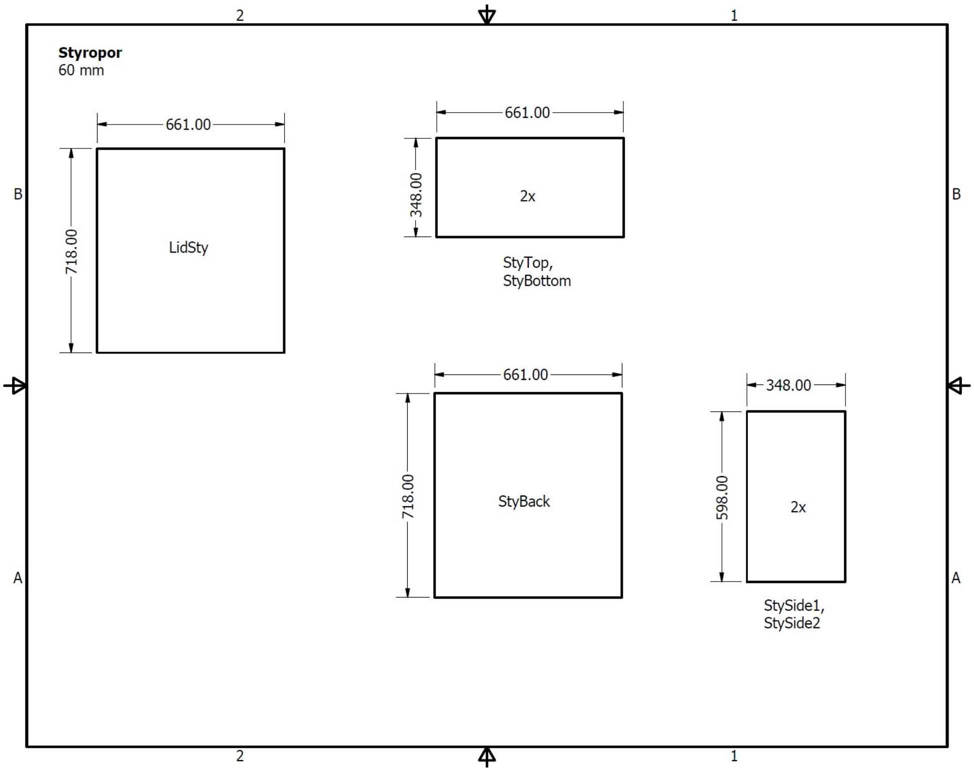


Figure 22: Drawings of all polystyrene insulation plates for the DDR

5.2.2 Construction and assembly

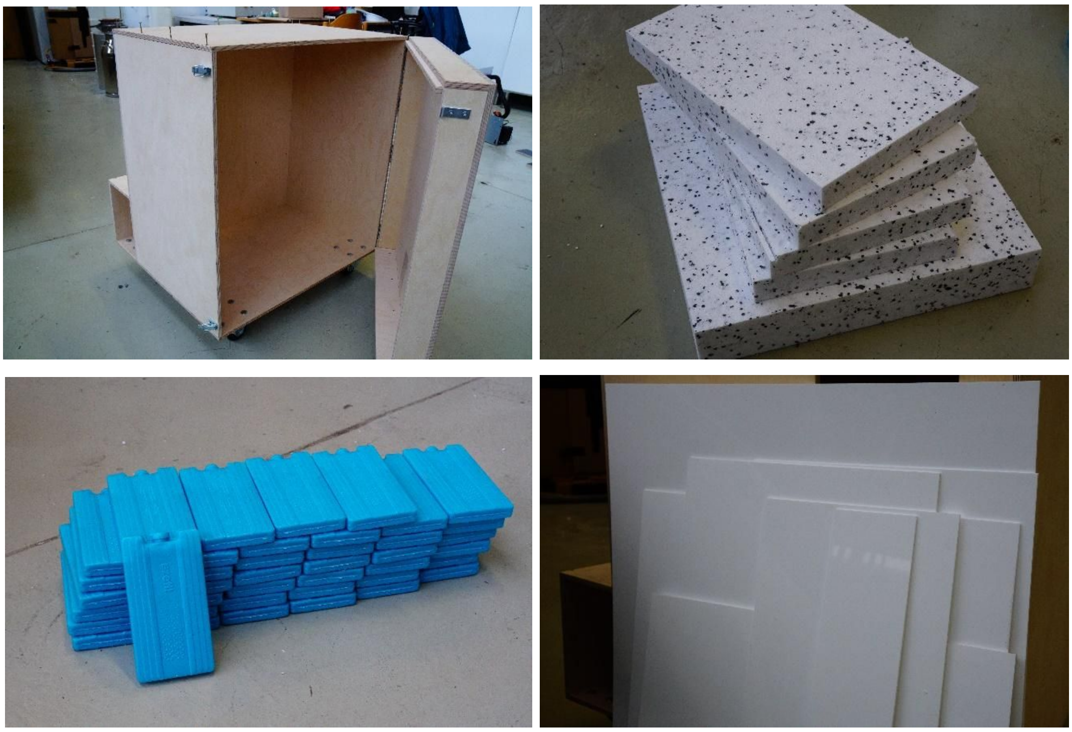


Figure 23: Wooden box (u.l.), polystyrene insulation material (u.r.), ice packs for ice storage around the evaporator (d.l.) and the acryl glass plates for the internal covering

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

5.2.3 Performance

Table 2: Experimental setup for testing the performance of the DDR

Ambient temperature:	30	°C
Water storage:	9.2	kg
Initial water temperature	22	°C
Ice formation time	15	h
Warming-up time (air < 15°C)	~ 30	h

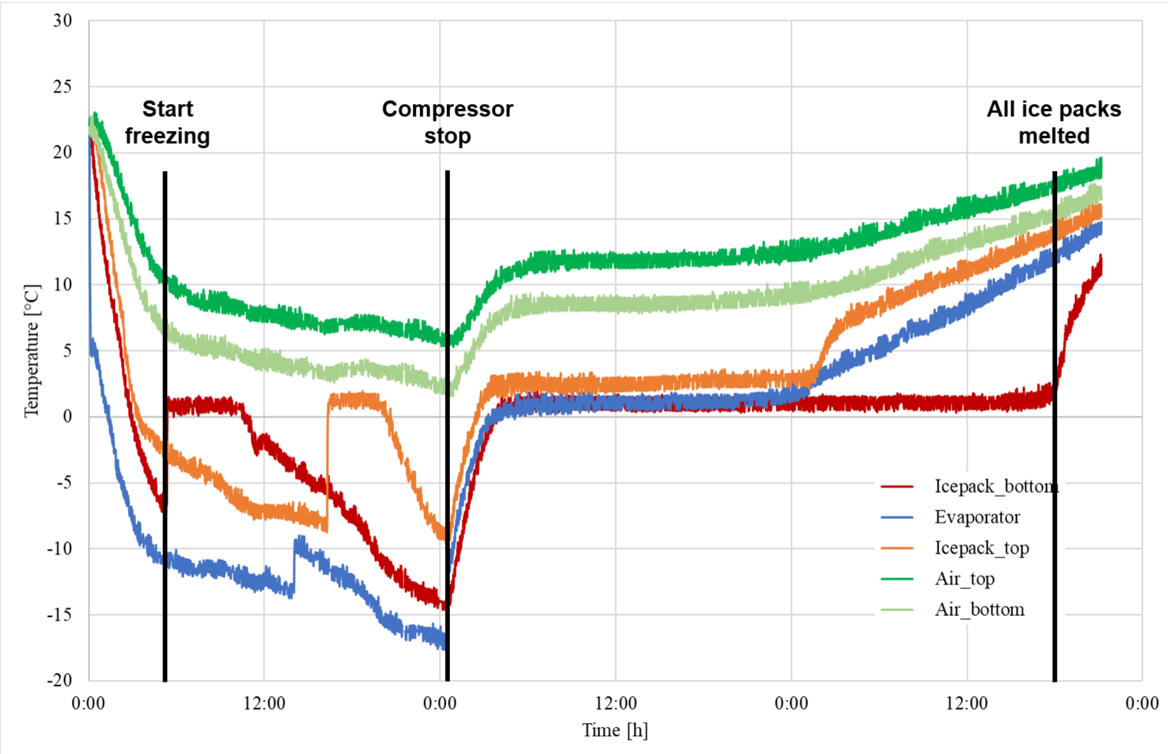


Figure 25: Cooling curves of the evaporator, ice packs and the room temperature of the refrigerator

5.3 Water chiller (Based on ice-storage)

Figure 26: Water chiller based on ice storage with cooling unit (u), the water distribution tube above the ice block at the evaporator (d.l.) and tubes for the external water circle (d.r.)

5.3.1 Drawings

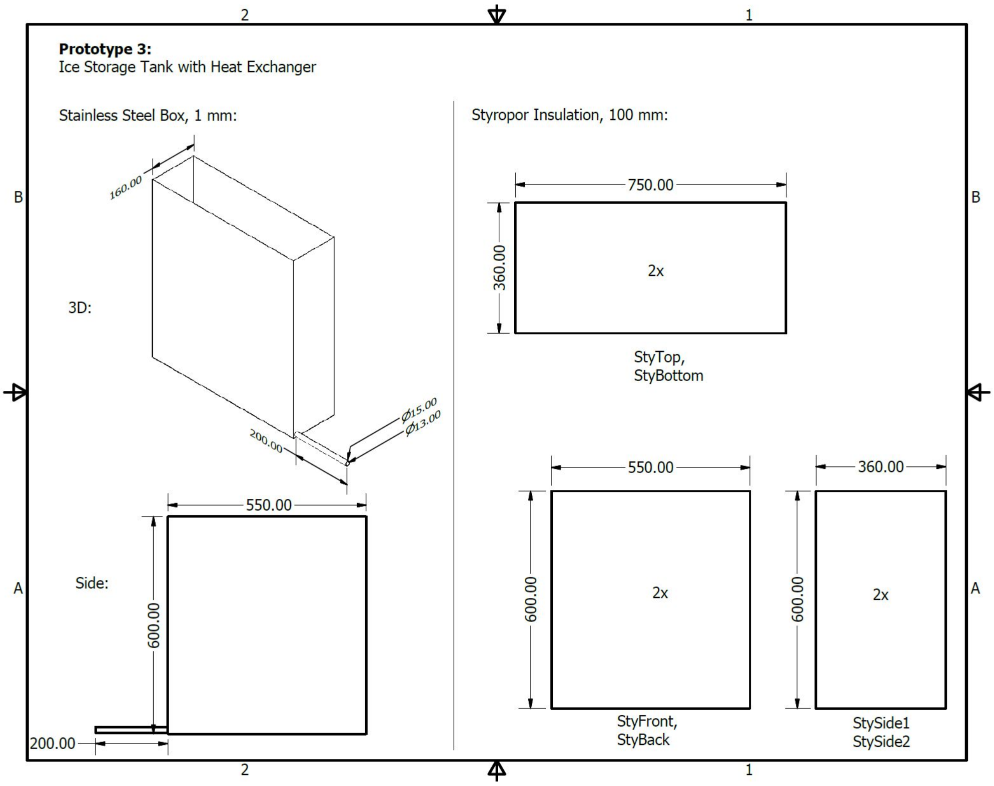


Figure 27: Drawing of the water filled metal box for the ice storage of the water chiller

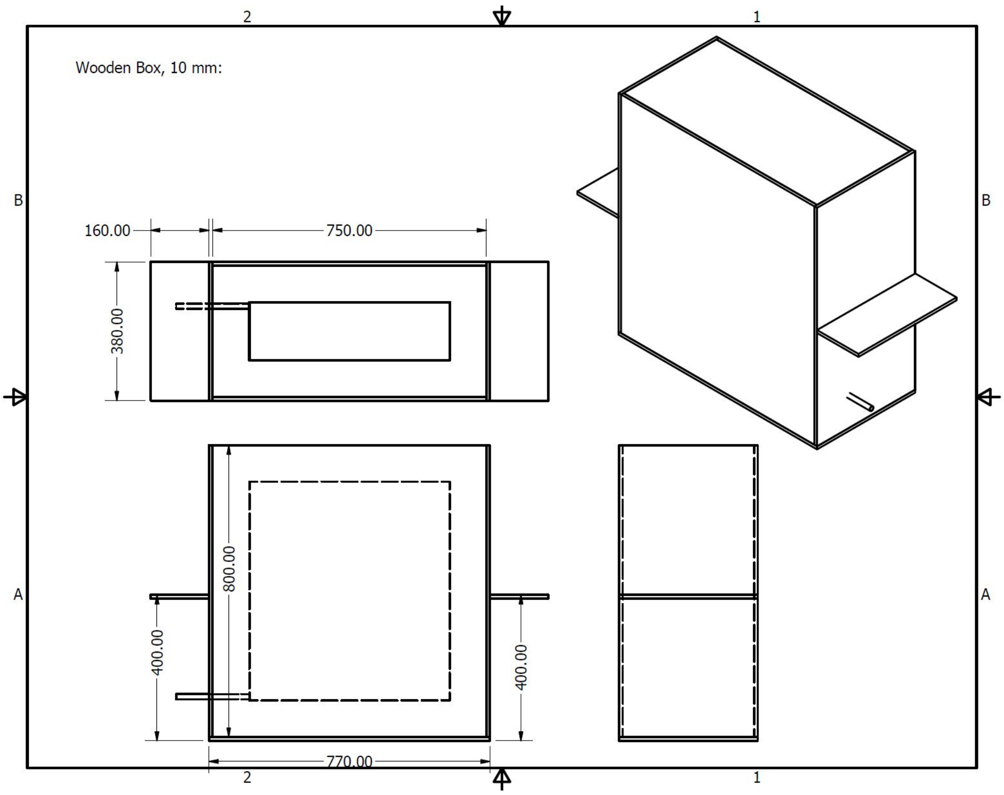


Figure 28: Drawing of the external wooden box of the water chiller

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.)

5.3.3 Applications

a) Cooling room

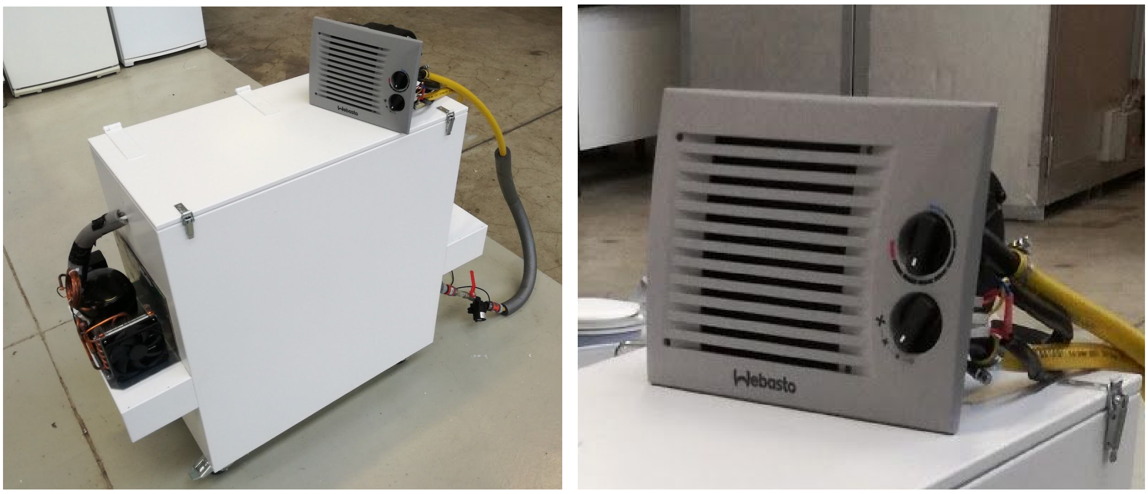


Figure 31: Cooling room application with an air heat exchanger

b) Water bath for milk cooling

Figure 32: Milk cooling application with waterbath cooling

5.3.4 Performance

a) Ice formation

Table 3: Experimental setup for testing the performance of the water chiller

Ambient temperature:	30	°C
Water storage:	95	kg
Initial water temperature	10	°C
Ice formation time	24	h
Total time	34.5	h

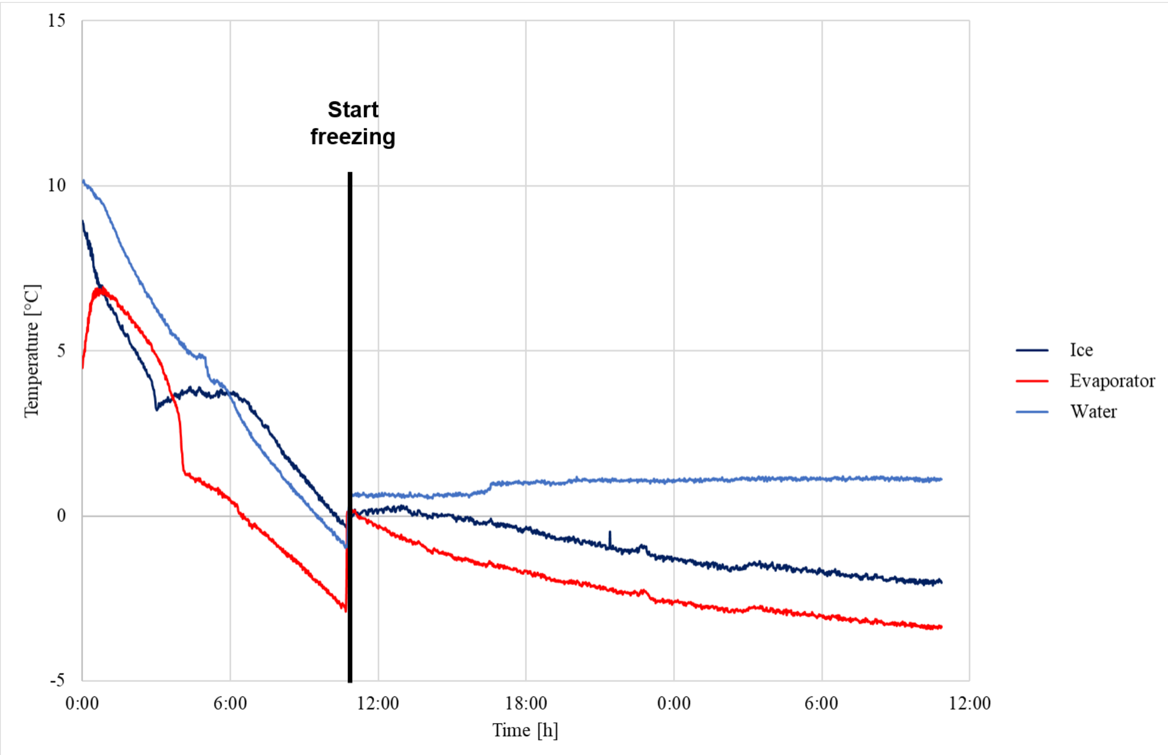


Figure 33: Cooling curves for evaporator, waterbath and ice temperature during the cooling and ice formation process

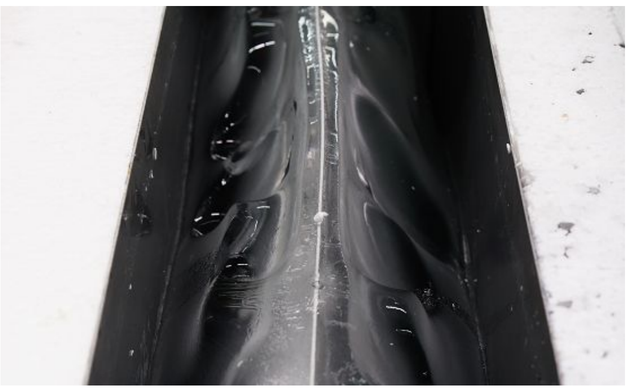


Figure 34: After 24 h ice formation process at the given experimental setups (see Table 3) an ice block of around 26 - 28 kg was formed

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

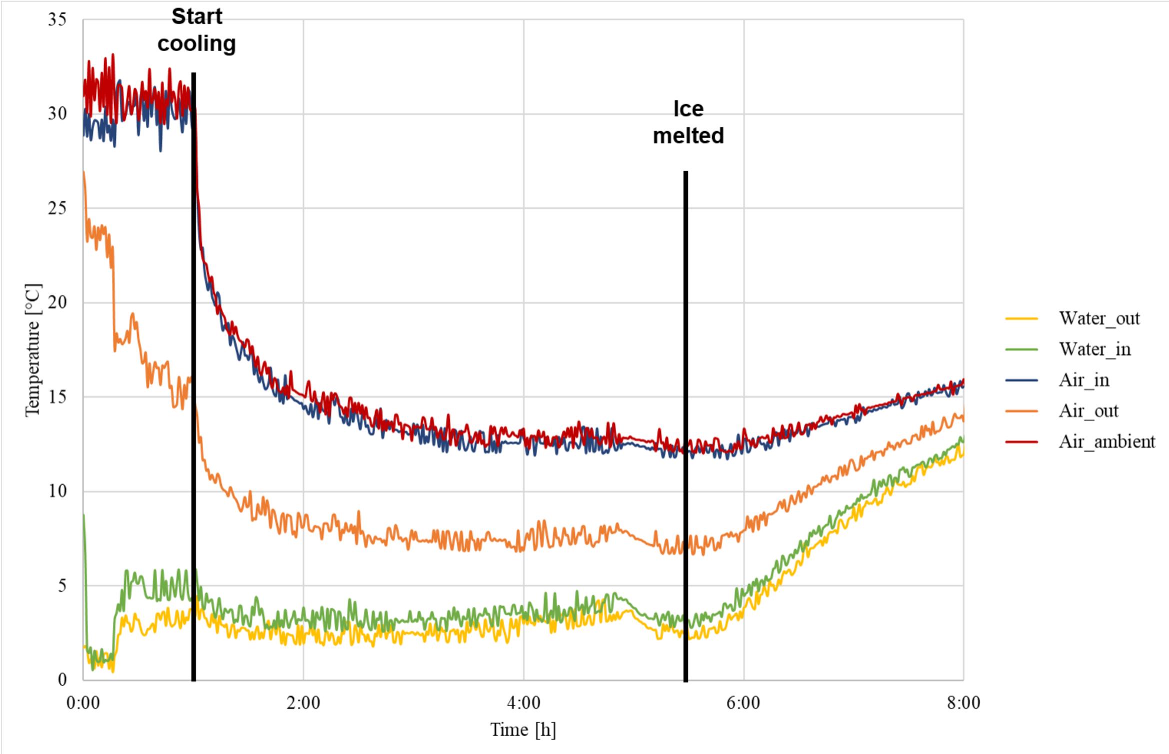


Figure 35: Cooling curves for cooling water and cooled air temperature at the cooling room application in the climate chamber. "Water_in" and "Water_out" show the water temperature at the inflow and outflow of the ice storage, respectively. "Air_in" and "Air_out" show the air inflow and outflow of the air heat exchanger, respectively.

Figure 36: Experimental setup for the experiment to test the performance of the cooling room application of the water chiller while discharging the ice block to cool the air in the climate chamber.

c) Discharge with water bath application

Table 5: Experimental setup for testing the performance of water bath application

Initial ambient temperature	~ 18	°C
Initial water bath temperature	10	°C
Ice mass	28	kg
Amount of "milk"	80	kg
Cooling time	2.5	h

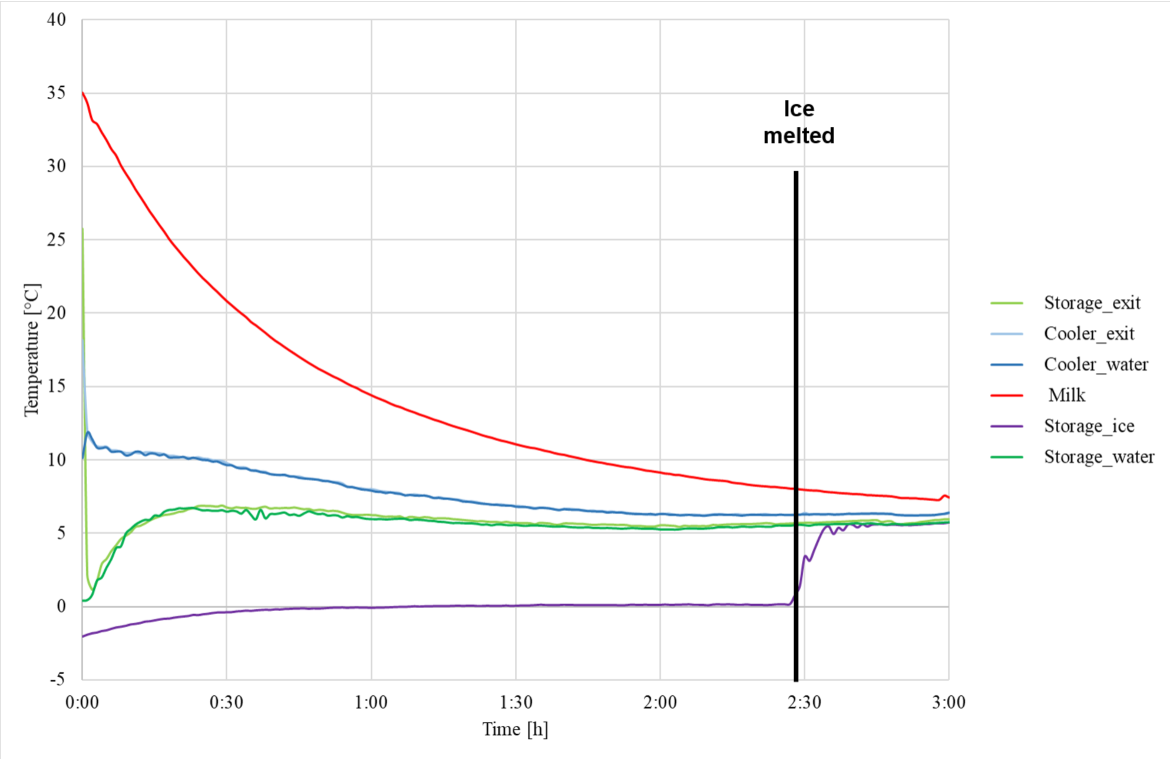


Figure 37: Cooling curves for the cooling water and ice temperature and the cooled milk temperature.

Figure 38: Experimental setup for testing the water bath application of the water chiller to cool down milk with the given settings (see. Table 5).

Glossary

SCU	Solar Cooling Unit
SSIM	Smart Solar Ice Maker
DDR	Direct Drive Refrigerator