WE HAVE MORE THAN 40 YEARS OF EXPERIENCE DEVELOPING DIRECT CURRENT COMPRESSORS AND HELPING CUSTOMERS BENEFIT FROM THE OPPORTUNITIES OF MOBILE REFRIGERATION TECHNOLOGY.

WITH IN-DEPTH KNOWLEDGE OF USE ACROSS VARIOUS APPLICATIONS, WE HAVE EARNED A POSITION AS MARKET LEADER, WORKING WITH OEM CUSTOMERS.

SECOP

SOLAR PANEL POWERED COMPRESSORS

TABLE OF CONTENT

1.
INTRODUCTION

This document is dedicated to customers, designers, consultants and others who want to gather information on how to start, design/build a solar powered refrigeration system using Secop BD compressors. Systems in question are limited to smaller systems where BD compressors are applicable.
This document should not be seen as a final document claiming to contain all information regarding solar powered refrigeration systems. Secop is in a continuous process to develop and improve the products offered within solar applications. This document will try to keep the focus on the compressor and electronic unit, where Secop has its core competence. Nor should this document be seen as a guideline to design an optimized solar refrigeration system. In the design of the other system components Secop recommends customers to seek information from the different manufactures of these components.

1.1 Applications/ Compressors/ Electronic units

The applications suitable for solar powering are basically not limited compared to a normal 12/24 V DC battery powered system. Limitations are normally given through:

- Cost
  Solar is more expensive compared to other energy sources.
- Sunshine
  Sun hours throughout the year.
- Location
  The distance between the panels and the application must not be to long due to the power supply wires. If the distance becomes too long the voltage drop becomes too large. If this must be compensated through a bigger square of the wires this could become a cost issue as well.
- Some applications suitable for solar:
  Refrigerators, freezers, vaccine coolers, ice creme freezers, bottle coolers

Compressors R134a R600a * R290 **	Code numbers	Electronic units (voltages & code numbers)								Application	
		Standard 12-24V DC 101N0210	EMI 12-24V DC 101N0220	High Start 12-24V DC 101N0230	High Speed 12-24V DC 101N0290	AEO EMI 12-24V DC 101N0320	Solar 10-45V DC 101N0400	AC/DC conv. 12-24V DC & 100 -240V AC 101N0500	Variable Speed 12-24V DC 101N2100	Refrigerators +32°C ambient	Freezers +32°C ambient
BD35F	101Z0200	✓	✓			✓	✓	✓		up to 200 litres	up to 200 litres
BD35F (inch con.)	101Z0204	✓	✓			✓	✓	✓			
BD50F	101Z1220	✓	✓	✓		✓		✓			
BD50F (inch con.)	101Z0203	✓	✓	✓		✓		✓			
BD35K *	101Z0211	✓	✓				✓				
BD80CN **	101Z0403			✓							
BD100CN **	101Z0401				✓						
BD1.4F-VSD	109Z0200								✓		

The above appliance sizes are guidelines only. The type and amount of insulation may vary between brands. In general 80 to 100 mm insulation is recommended. 60 mm insulation is not recommended from the perspective that the holding time of the temperature is too poor in a situation without sunshine.

1.2 WHO specifications

A very suitable solar application is vaccine coolers. These coolers are built to meet the WHO specifications. The demands and test procedures can be found on WHO´s web page www.who.org. Some important demands are:
At ambient +32 °C the following must be fulfilled:

- Vaccine temperature must be stored within +3 til +8 °C
- Hold-over-time: 5 days (without adding energy)
- Energy consumption must be lower than 0.70 kWh/ 24 h + 0.10 kWh/24 per 10 liter above 50 litres.

2.
SYSTEM CONCEPTS

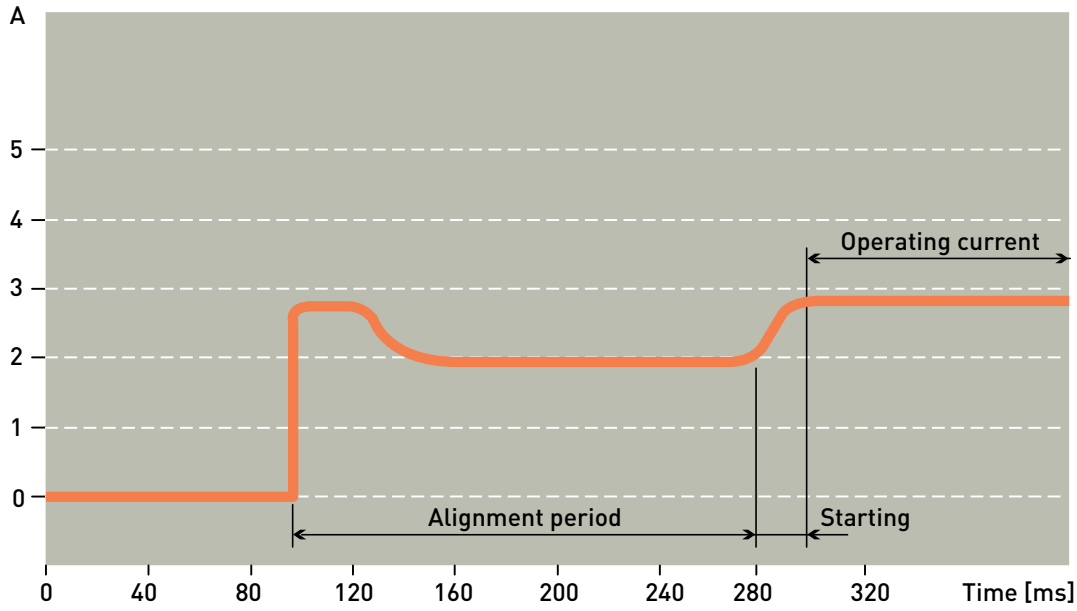
2.1
Evaporators

There are no special demands to evaporators used in a solar powered system. Standard evaporators can be used. The design of the evaporator will depend on the applications

2.2
Direct solar operated system

It is important to know the starting current of the compressor for the selection and sizing of the solar panel. Secop offers a dedicated solar electronic with a built in soft start function that reduces the starting current. See curve below.
This means that the selection / sizing of the panel must be done based on the cooling demand. Secop recommends a 120 W solar panel. The power consumption of the compressor can be found in the datasheet. The code number for this dedicated electronic unit is 101N0400.

Starting current for standard electronic 101N0400:

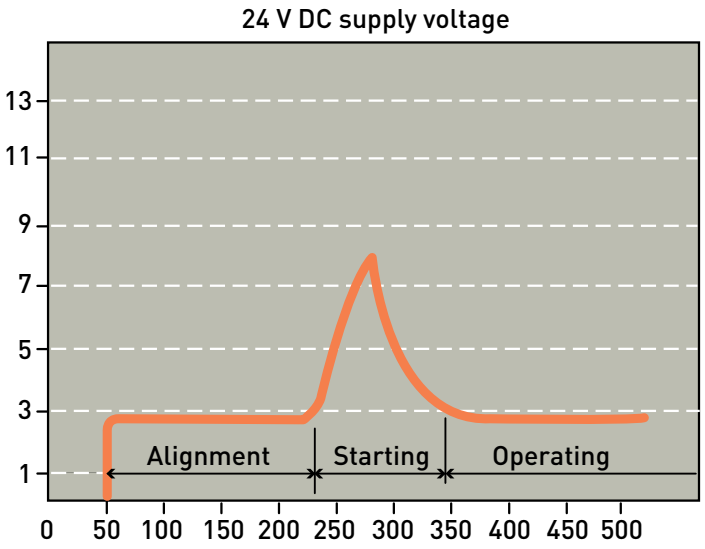


The electronic unit 101N0400 has a built in function called Adaptive Energy Optimization (AEO). This automatically adjusts the speed and thereby the capacity of the compressor. The capacity is adjusted so that the thermostat runtime is approx. 30 minutes under all load conditions.

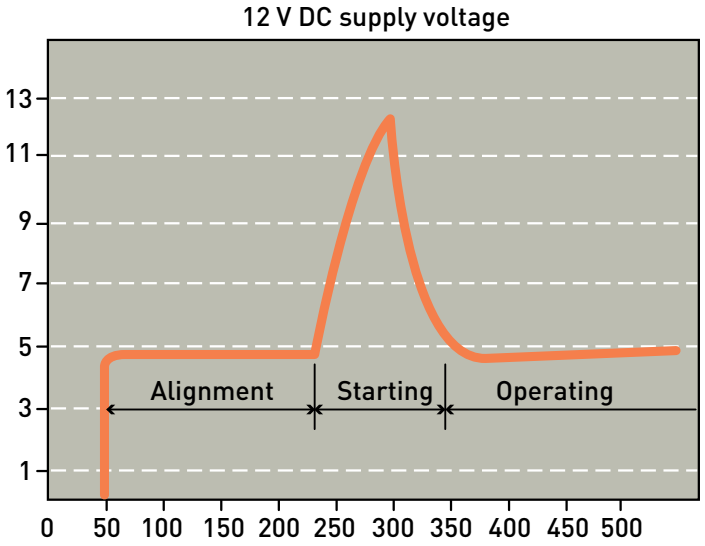
2.3 Battery assisted system

In a battery assisted system a standard elecronic unit 101N0210 should be used, as the starting current is not an important issue.

Starting current for standard electronic 101N0210 with 12 V DC:



Starting current for standard electronic 101N0210 with 24 V DC:



The alignment period is used to define the position of the rotor. Hereafter the start begins.

2.4 Adjustment of capacity

Alternatively this can be adjusted manually by a resistor in the thermostat circuit. Please refer to the instructions to select the resistor. If the system is designed with an ice bank, it is preferable to run maximum capacity when sun power is available. In this case the speed should be manually kept at max 3500 rpm.

3.
SOLAR PANELS

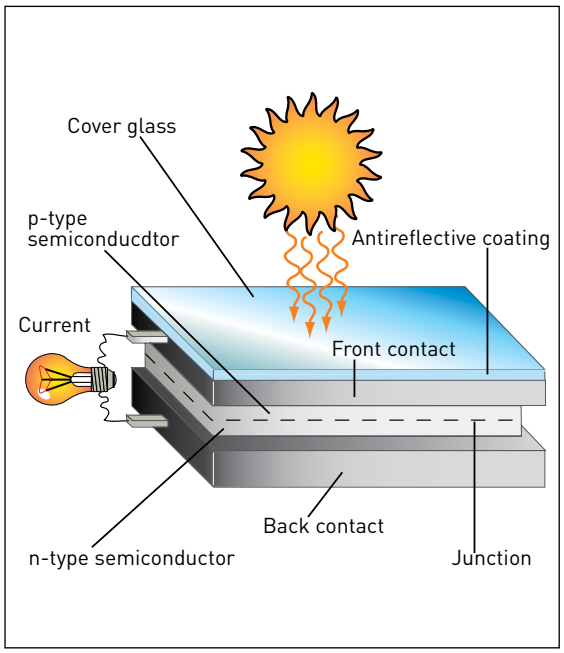
Solar panels also called Photo Voltaic (PV) panels are in principle a semiconductor. A schematic of a PV cell is shown below.

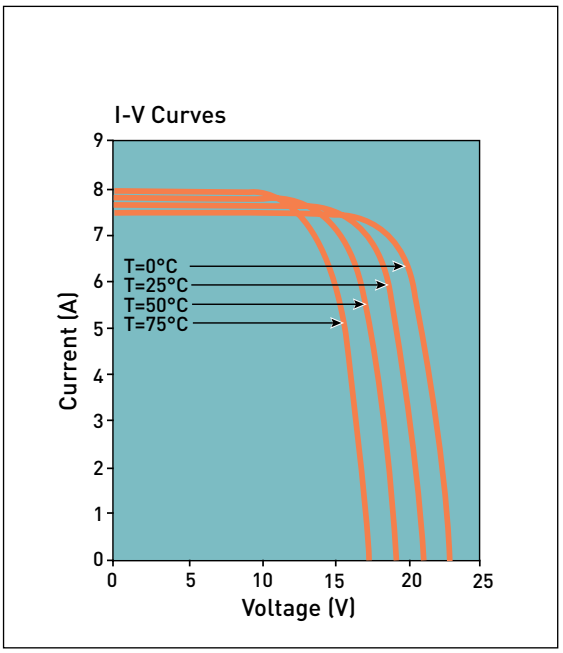
Direct solar powered
In applications where Secop BD compressors are used we recommend a panel capacity of approx. 120 watt. If the cooling capacity is bigger than 120 watt a bigger panel must be selected to match the cooling demand.

Battery assisted
In a combi system with PV panels and batteries, the size of the PV panel offen depends on æsteisk and how big a contribution is wanted from the PV panel of the total powersupply. Typically a panel betweeen 40-80 W is recommended. Price wise a rule of thumb says $ US 1-2 per watt. The figure may differ between brands and countries and quantities bought.

The current and power outputs of PV modules are approx. proportional to sunlight intensity. At a given intensity, a module's output current and operating voltage is determined by the characteristics of the load. If that load is a battery, the battery's internal resistance will dictate the module's operating voltage.
A module which is rated at 17 volt will put out less than its rated power when used in a battery system.
This is because the working voltage will be between 12 and 15 V. As wattage is the product of volt times amperes, the module output will be reduced.
For example: a 50 watt module working at 13 volt will produce 39 watt (13 volt x 3 amps) = 39 watt. The amps are found by dividing 50 watt /17 volt = 3 amps.

An I-V curve as illustrated below is simply all of a modules possible operating points (voltage/current combinations) at a given cell temperature and light intensity. An increase in cell temperature increases current slightly, but drastically decreases in voltage.
Maximum power is derived at the knee of the curve.





3.1 Example of specifications from a PV manufactures catalogue

Rated Power	(Watts)	167.0	158.0	125.0	120.0	80.0	70.0	60.0	50.0	45.0	40.0	35.0
Current of Max. Power	(Amps)	7.2	6.82	7.2	7.1	4.73	4.14	3.55	3.00	3.00	2.34	2.33
Voltage at Max. Power	(Volts)	23.2	23.2	17.4	16.9	16.9	16.9	16.9	16.7	15.0	16.9	15.0
Short Circuit Current	(Amps)	8.0	7.58	8.0	7.45	4.97	4.35	3.73	3.1	3.1	2.48	2.5
Open Circuit Current	(Volts)	28.9	28.9	21.7	21.5	21.5	21.5	21.5	21.5	19.2	21.5	188
Length	(Inches)	50.8	50.8	56.0	56.0	38.4	34.1	29.6	25.2	22.6	20.7	18.5
Width	(Inches)	39.0	39.0	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
Depth	(Inches)	1.4	1.4	2.0	2.0	2.0	2.2	2.0	2.1	2.1	2.0	2.0
Shipping Weight	(lbs.)	35.3	35.3	30.0	30.0	25.0	19.0	20.0	16.0	15.0	16.0	10.6

3.2 Capacity vs size

As a rule of thumb the size of a 150 W panel is 1 m², 75 W panel 0.5 m² etc.

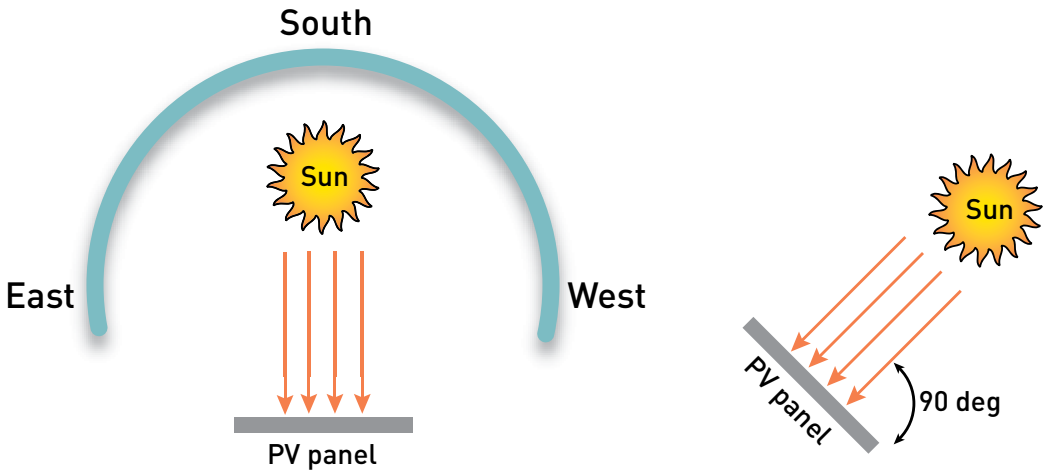
3.3 Voltages

The Secop BD35F and BD35K compressors can handle a voltage range between 10 and 45 V DC, using the dedicated solar electronic, code no 101N0400.
Using the standard electronic units 101N0210 or 101N0500 a 220 kΩ resistor must be mounted between terminal C and P. The voltage range will then be from
9.6 to 31.5 V DC
All PV manufactures offer datasheets containing I-V curves. These I-V curves show the relation between Voltage and Amperes. See the example on page 6.
At no load on the panel the voltage is relatively high compared to the voltage at a loaded panel.

When using a BD1.4F-VSD with electronic unit 101N2100, solar mode can be chosen via menu in TOOL4COOL® or external resistors.

3.4 Orientation of the panels

In order to get the maximum capacity out of the solar panels it is important that the panels have the right position compared to the sun.
The pictures below show how to orientate the panels in the northern hemisphere.



3.5 Manufactures

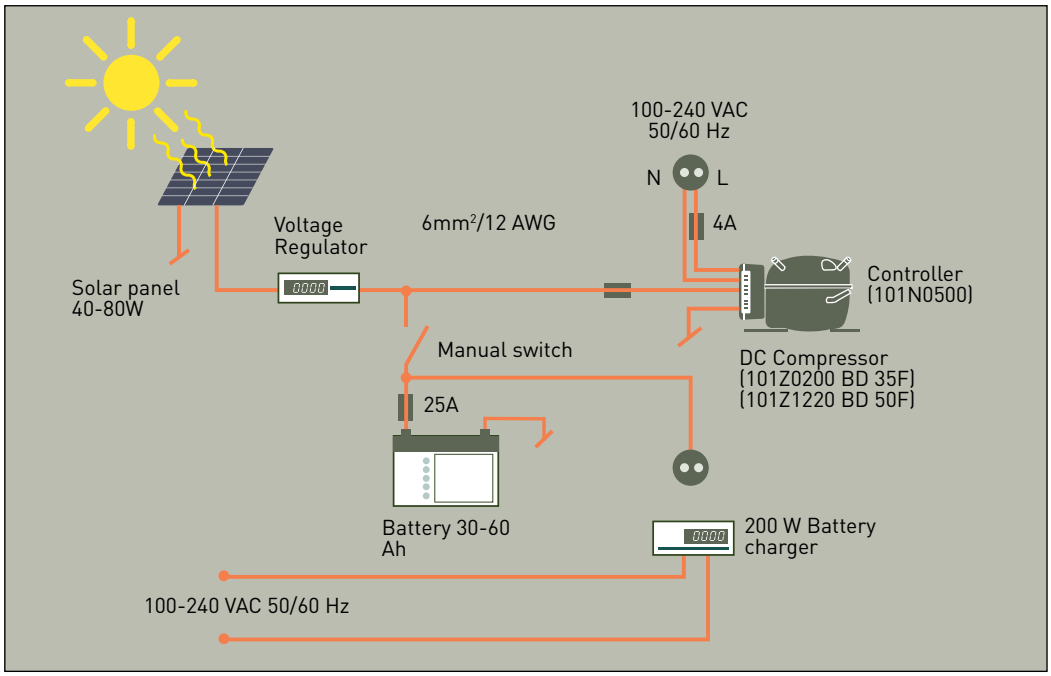
On the market there is a huge amount of solar panel manufactures. Using a search engine on the web will bring you a lot of manufactures.
Secop does not have a preference for a particular brand or manufacture.

Below we have listed some of the major suppliers. Through the web you will be able to enter their homepages and find further details.

Company	Country	Website
Bosch	Germany	www.bosch-solarenergy.com
Sovello	Germany	www.sovello.com
Sharp	Japan	www.sharp-solar.com
BP Solar	UK	www.bpsolar.com
Kyocera	Japan	www.kyocerasolar.com
SolarWorld	Germany	www.solarworld.de
Schott Solar	Germany	www.schott.com
Isofoton	Spain	www.isofoton.com
Panasonic	Japan	www.panasonic.net/energy/solar
Mitsubishi	Japan	www.mitsubishielectric.com/bu/solar
Photowatt	France	www.photowatt.com

4.
BATTERIES

Battery assisted system
The size of the battery bank required will depend on the storage capacity required, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used. When designing a power system, all of these factors are considered.
It is recommended to use solar batteries or deep cycle batteries.

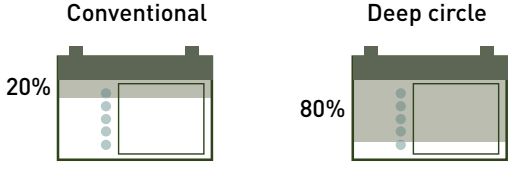


4.1 Lead-acid batteries

Lead
Lead-acid batteries are the most common in PV systems because their initial cost is lower and they are readily available nearly everywhere in the world. There are many different sizes and designs of lead-acid batteries, but the most important is whether they are deep cycle batteries or shallow cycle batteries.

Shallow cycle batteries, like the type used as starting batteries in automobiles, are designed to supply a large amount of current for a short time and stand mild overcharge without losing electrolyte. Unfortunately, they cannot tolerate being deeply discharged. If they are repeatedly discharged more than 20 percent, their life will be very short. These batteries are not a good choice for a PV system.

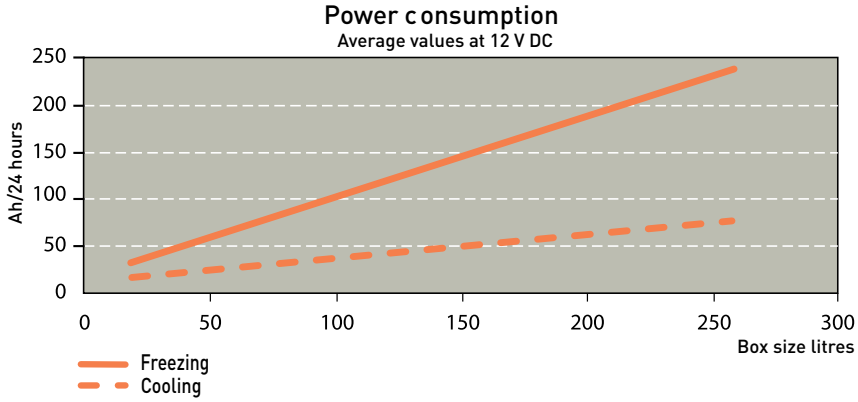
Solar
Deep cycle batteries are designed to be repeatedly discharged by as much as 80 percent of their capacity so they are a good choice for power systems. Even though they are designed to withstand deep cycling, these batteries will have a longer life if the cycles are shallower. All lead-acid batteries will fail prematurely if they are not recharged completely after each cycle. Letting a lead-acid battery stay in a discharged condition for many days at a time will cause sulfation of the positive plate and permanent loss of capacity.



4.2 Sealed deep-cycle lead-acid batteries

They are maintenance free. They never need watering or an equalization charge. They cannot freeze or spill, so they can be mounted in any position. Sealed batteries require very accurate regulation to prevent overcharge and over-discharge. Either of these conditions will drastically shorten their lives. They can be for remote, unattended power systems, but also for any client who wants the maintenance free feature and doesn't mind the extra cost associated with these batteries.

A guideline on how to size the battery is shown in the graphs below. The curves are only a guideline, and the consumption may vary depending on ambient temperature, insulation of the appliance etc.



BD power consumption at 25°C ambient.

It is not possible to give a figure on that due to the fact that the consumption depends on many things. Including:

- Load on the system
- Insulation of the cabinet
- Size of the cabinet
- Ambient temperature
- Evaporating temperature
- Condensing temperature

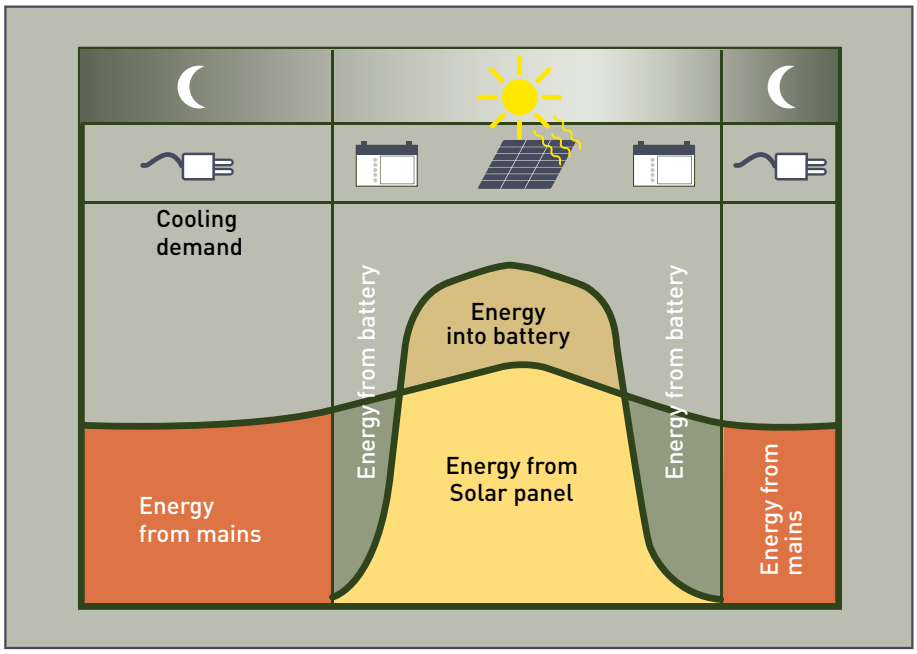
The factors which determine how fast the battery is drained are:

- Size in Ah (ampere hours)
- Shape of charge condition
- Ambient temperature
- Other consumptions in an idle stop situation

The graphs show an average as a function of the cabinet size.

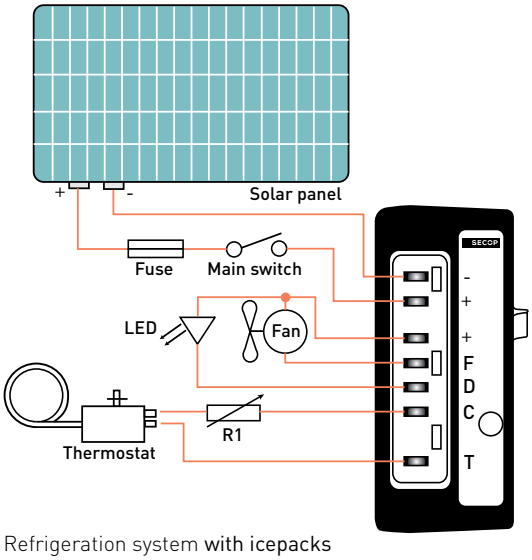
Only take this as a guideline.
The factors mentioned above all have an influence, which can create a deviation from the graph.

4.3. Energy flow

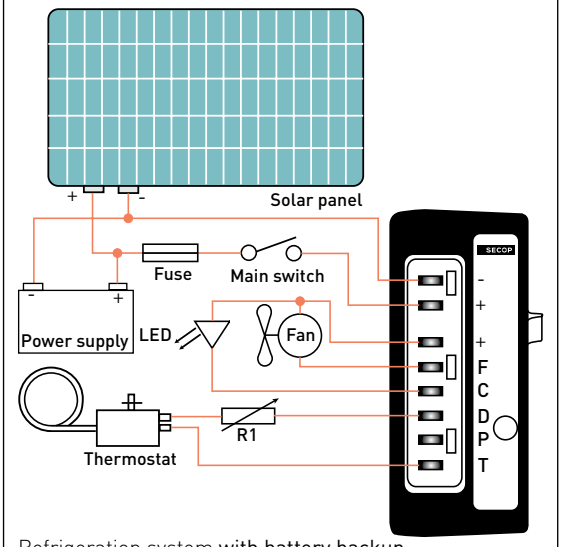


5.
ICE PACK SYSTEM

Direct solar operated system vs. battery package
The ice packs are an alternative to a battery package. The advantage of the ice packs are that they are maintenance free. The ice packs can be an integrated part of the appliance design or can simply be plastic bags that are put into the appliance.



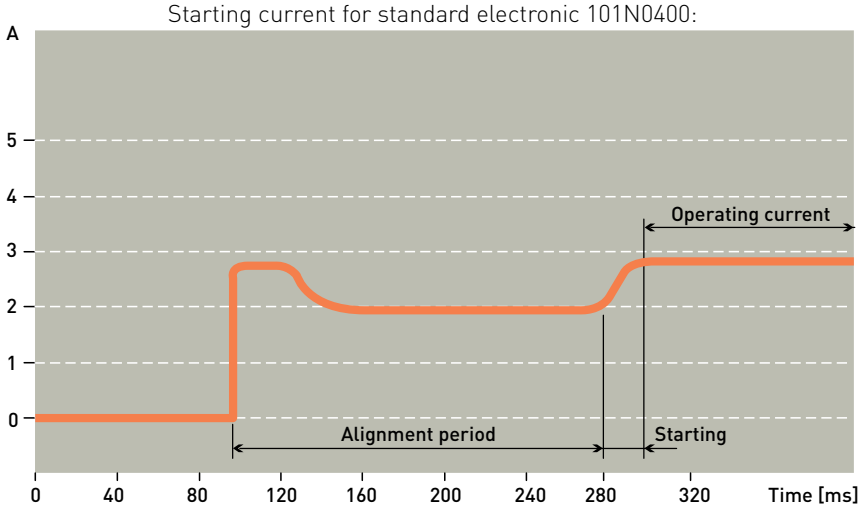
Refrigeration system **with icepacks** using BD35F/35K solar electronic unit 101N0400



Refrigeration system **with battery backup** using BD35F electronic unit 101N0210

The main differences between 101N0400 and the standard electronic 101N0210 are:
- Terminal P has been removed.
- Voltage range 10 to 45 V DC
- No load dump protection
- Starting current reduced
- Can start and operate on a solar panel down to 70 W (120 W recommended)

Starting current for standard electronic 101N0400:



5.1 Dimensioning of ice packs

The size or amount of ice packs that should be used is a compromise between active space in the appliance and desired hold over time. As an example we have illustrated the capacity of 1 kg water:

1 kg H_20 ~ 92.9 Wh ~ 30 W cooling capacity for 3 hours.

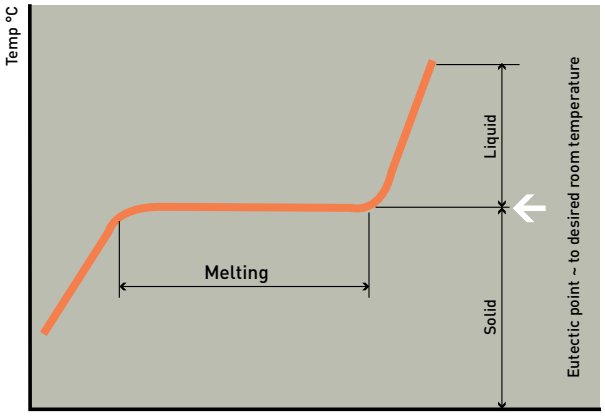
The eutectic point is the melting point of the liquid inside the eutectic plates. The mixture of the liquid must be choosen so that the melting point corresponds to the desired room/box temperature. See graph below.

Box
150 litres cooling box ~ 50 Ah/24 h
50 AH ~ 2.1 Ah/h
2.1 A X 12V = 25.2 W average
25.2 X 24 ~ 605 W/24 h

Compressor BD35F
Power consumption compressor 60 W
Run time ~ 605/60 ~ 10.1H ~ 42%

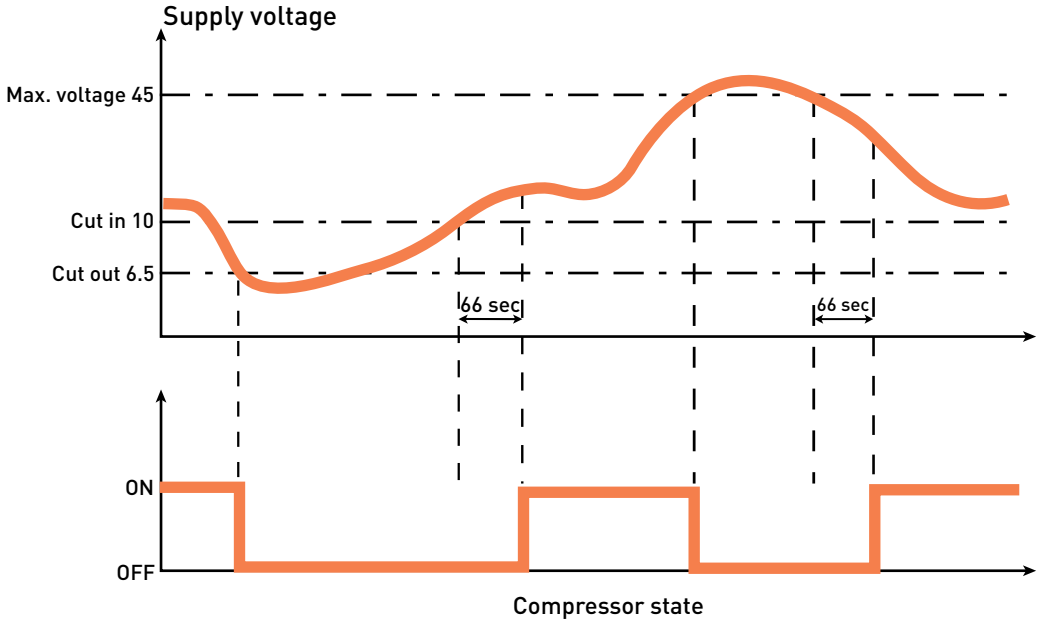
Solar panel
Contributes 8 hours/24 h ~ 605* 0,33 = 201 W

Icepacks
605-201 = 404 W ~ 404/93 ~ 5 kg ice ~ 16 hours without compressor operation



Example how to size the icepack

5.2 Voltage range electronic unit 101N0400



6.
THERMOSTAT/ VOLTAGE REGULATOR

6.1 Thermostat BD35F/BD35K

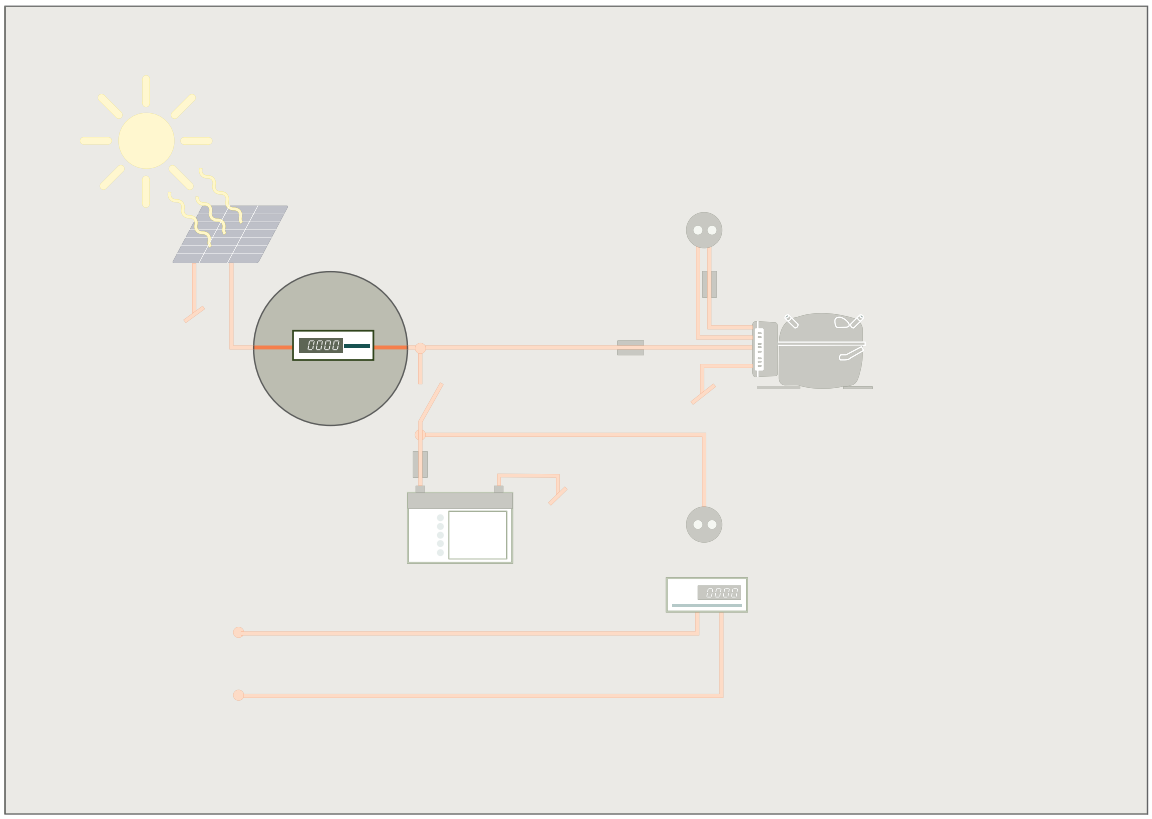
The thermostat in a solar system can be a mechanical or electronic thermostat. If a system with a battery power back up is used, it should be considered not to have a difference on the thermostat too small. If the difference is too small the compressor will make more start / stops which in the end can drain the battery quicker. If an ice pack system is used the set point of the thermostat should be chosen not too high. The set point should be so low that the eutectic point of the ice packs is reached.

6.2 Thermostat BD1.4F-VSD

In the BD1.4F-VSD there is a built in electronic thermostat that can be used together with a NTC sensor. The setpoint can be programmed via TOOL4COOL® or external resistors.

6.3 Voltage regulator/ Power tracker

In order to utilize the full power from a PV panel it is recommended to mount or voltage regulator or powertracker. Suppliers can be found on the web.



7.
SOLAR ASSISTED ICE CREAM CABINET

During the Olympic Games in Sydney, Australia 2000, ice cream cabinets using hydrocarbon (HC) refrigerants were tested. These have been subsequently rolled out in large numbers in Europe.

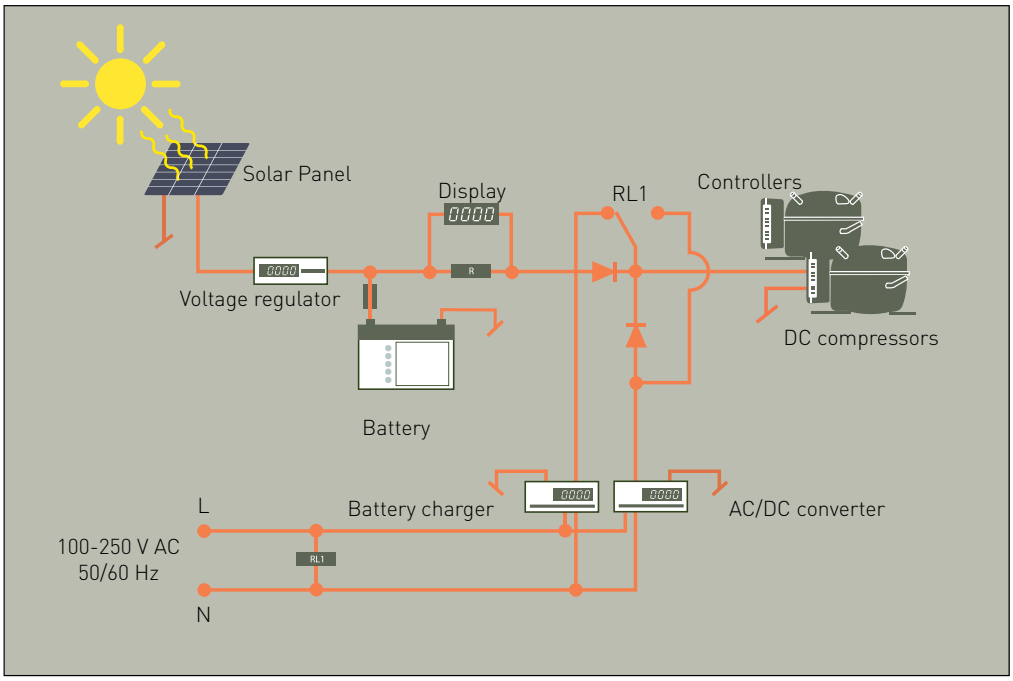
An extension of the project has been to investigate whether solar panels could be used to reduce energy consumption. This project was run jointly with Secop (Danfoss Compressor then), who developed a compressor using HC refrigerant, that was capable of running on DC power supply with a low power requirement on start up and running so that it could be used with solar panels and a battery.
These compressors were fitted in an Ice Cream Cabinet where part of the energy supply comes from a 80 W solar panel, and the remaining part is coming from a 130 Ah solar deep cycle maintenance free battery. Initial tests suggest that it is capable of maintaining the temperature inside the cabinet even at +50 °C ambient temperatures.

During the Athens Olympic Games and the autumn, four of these Ice Cream cabinets were located at strategic places in the centre of Athens.

Ice cream cabinets using environmentally friendly HFC-free refrigerants with low power requirement.

7.1 Energy supply

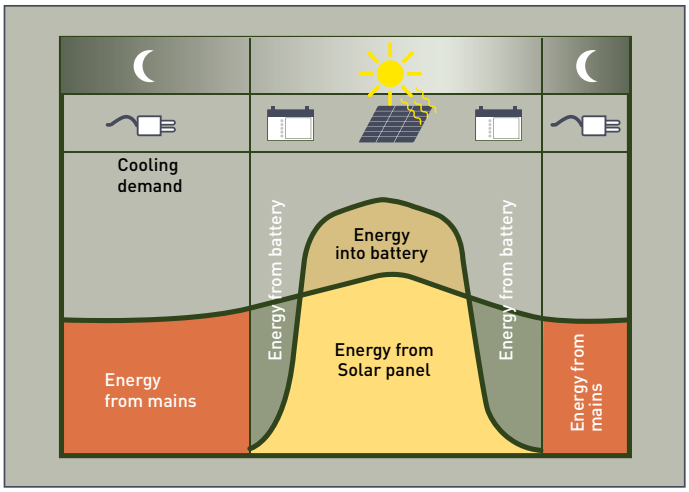
During the night the cabinets are moved to a place with mains supply to charge the batteries.



Energy supply diagram

7.2 Energy flow

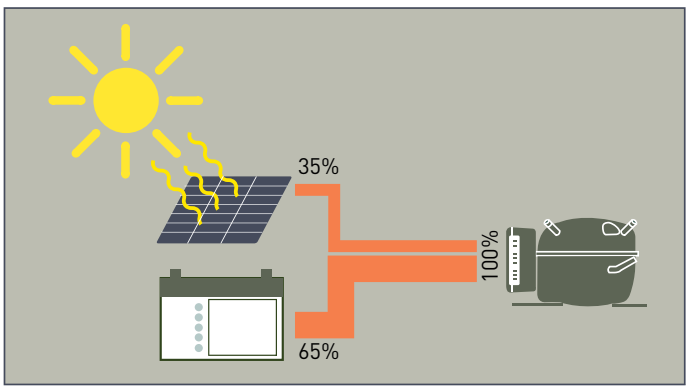
During the day the solar panels deliver a surplus of energy which is charged into the battery.



Energy flow in the cabinet over 24 hours

7.3 Solar contribution

The size of the solar panel has been chosen to deliver a contribution from the PV panel is approx. 35 % of the total energy consumption of the cabinet.



Solar contribution per 24 hours

8.
PERFORMANCE DATA

Compressors R134a R600a * R290 **	Capacity [W] at max. speed *** EN12900 Household/CECOMAF | ASHRAE Evaporating temperature [°C]													
	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0	5	7.2	10	15
BD35F			26.2 | 32.2	35.9 | 44.2	40.4 | 49.7	50.5 | 62.2	69.8 | 86.0	93.6 | 115	122 | 150					
BD50F			36.7 | 45.2	52.2 | 64.4	58.3 | 71.9	71.4 | 88.2	94.9 | 117	123 | 152	157 | 194					
BD35K *			24.9 | 30.3	36.0 | 43.8	40.2 | 49.0	49.3 | 59.9	65.1 | 79.2	83.8 | 102	106 | 129					
BD80CN **	31.3 | 34.9	45.3 | 50.5	62.1 | 69.2	82.0 | 91.0	90.0 | 100	105 | 118	133 | 148	164 | 184						
BD100CN **	44.6 | 49.7	62.4 | 69.6	83.4 | 93.0	108 | 121	117 | 131	137 | 153	170 | 190	209 | 233						
BD1.4F-VSD			12.1 | 15.4	22.8 | 28.6	27.1 | 33.9	36.2 | 45.1	52.2 | 64.9	70.8 | 88.0	92.1 | 114	116 | 144				

Compressors R134a R600a * R290 **	Code numbers	Power consumption [W] at max. speed *** Evaporating temperature [°C]													
		-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0	5	7.2	10	15
BD35F	101Z0200			36.0	42.8	45.4	50.8	59.5	68.9	78.5					
BD50F	101Z1220			47.0	59.0	63.0	70.7	82.6	95.0	108					
BD35K *	101Z0211			35.1	42.7	45.2	49.7	56.4	63.0	69.7					
BD80CN **	101Z0403	46.9	54.8	63.2	72.0	75.0	80.8	89.3	97						
BD100CN **	101Z0401	57.4	69.1	80.8	92.5	96.4	104	115	125						
BD1.4F-VSD	109Z0200			26.6	33.8	36.2	40.8	47.8	54.7	61.4	68.1				

*** Please refer to the individual compressor data sheets for the complete application range.

BD
SOLAR

BD80/100CN
R290, -40°C, -10°C evap. temp.
Freezer application, solar-powered systems, ice cream boxes up to 200 l, 20-164 W / 31-209 W cooling capacity*.

BD35K Multivoltage and BD50K
R600a, -30°C, +10°C evap. temp.
Solar-powered applications, etc., 100-250 l coolers, 13-242 W cooling capacity*. BD35K can be powered with AC and DC, 85-240 V AC 50/60 Hz, 12-24 V DC, automatic selection of AC when available.

BD1.4F-AUTO.3 and BD1.4F-VSD.2
R134a, -30°C, +5 and +15 / 0°C evap. temp.
In-car cabinets and all mobile applications for portable boxes, boats, trucks, etc., 14-108 W and 7-218 W / 5-85 W cooling capacity*.

BD350GH
R134a, -25°C, +15°C evap. temp.
Tailored for spotcooling systems in sleeping compartments in trucks, caravans, golf buggies, etc., 85-786 W cooling capacity*.

BD250GH.2
R134a, -25°C, +15°C evap. temp.
Designed for cabin cooling in trucks during nighttime, very silent operation, 31-446 W cooling capacity*.

BD35F/50F Multivoltage
R134a, -30°C, +10°C evap. temp.
All mobile applications for portable boxes, boats, trucks, etc., can be powered with AC and DC, 85-240 V AC 50/60 Hz, 12-24 V DC, automatic selection of AC when available, 15-152 W / 20-191 W cooling capacity*.

BD35F/50F/80F Basic
R134a, -30°C, +10°C evap. temp.
All mobile applications for portable boxes, boats, trucks, etc., 15-152 W / 20-191 W / 35-221 W cooling capacity*.

TOOL4COOL®
Flexible control settings

TOOL4COOL® Software
Tool4Cool® is a unique PC software tool that enables you to precisely configure your Secop BD compressors to your cooling systems.
Via microprocessor-based controllers, Tool4Cool® gives you easy access to all parameters. These can be changed, monitored, downloaded or uploaded to get the optimum performance out of your cooling system.

* EN12900/CECOMAF conditions:
Condensing temp.: 55°C | Suction gas temp.: 32°C | Ambient temp.: 32°C, | Liquid temp.: no subcooling

OUR JOURNEY SO FAR

1956 Production facility and headquarters in Flensburg, Germany founded.

1958 Start of production for PW compressors.

1970 Introduction of SC compressors. The birth of a standard-setting platform in the light commercial market.

1972 Introduction of FR compressors.

1977 Introduction TL and BD compressors.

1990 Introduction of NL compressors.

1992 Introduction of PL compressors.

1993 Start of production with natural refrigerant R600a (isobutane). Production facility in Crnomelj, Slovenia founded.

1999 Start of production with natural refrigerant R290 (propane).

2002 Production facility in Zlate Moravce, Slovakia founded.

2005 Introduction of GS compressors.

2008 Production facility in Wuqing, China founded.

2010 Introduction SLV-CNK.2 and SLV-CLK.2 variable speed compressors. Introduction BD1.4F Micro DC compressor. Introduction of DLX and NLU compressors.

2013 Introduction of the XV compressor - opening a new chapter in refrigeration history. Secop acquires ACC Fürstenfeld, Austria.

2015 New generation of energy-efficient propane compressors. New variable speed platforms for household and light commercial applications.

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