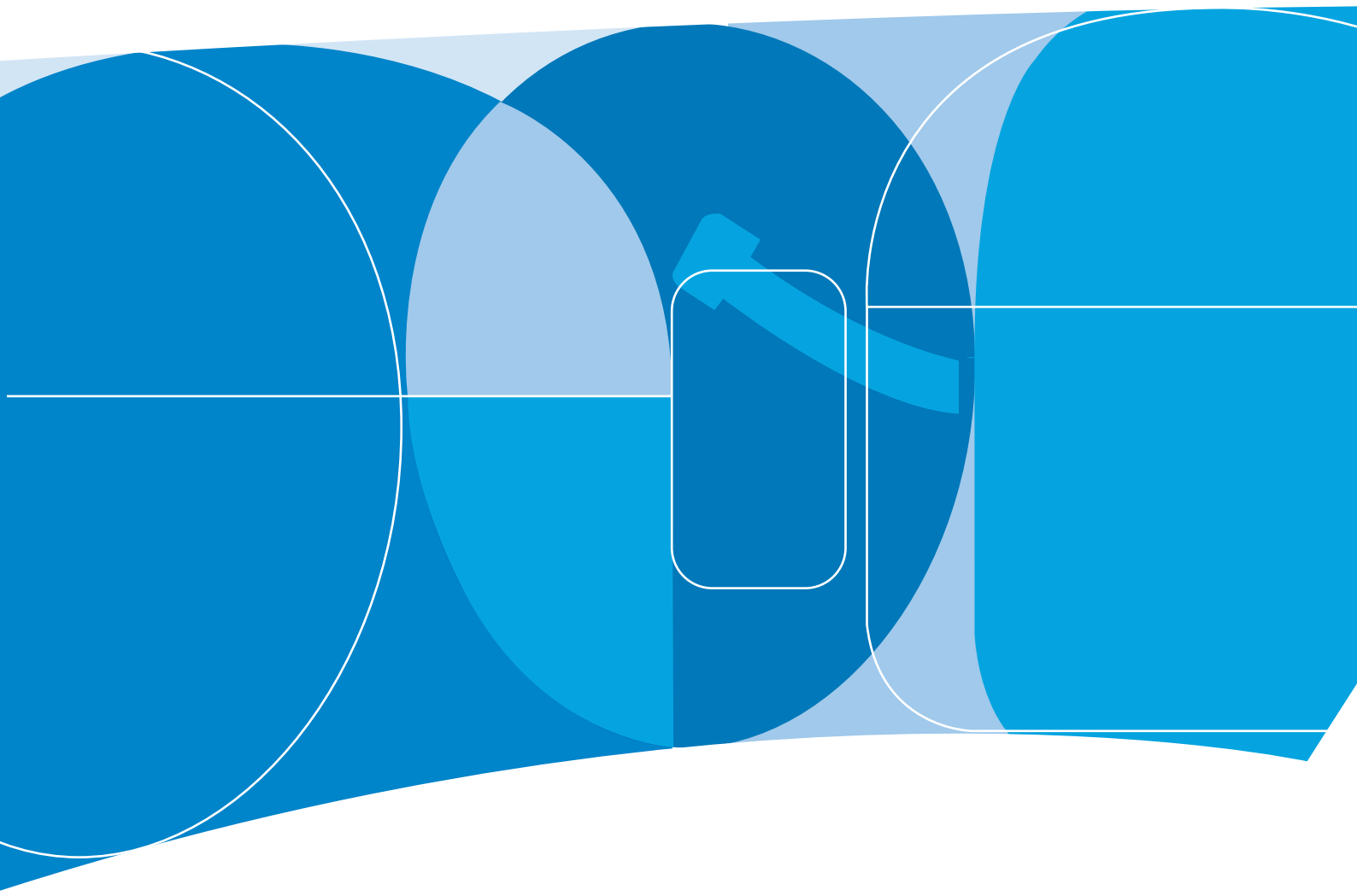


How to get started
Danfoss Compressors – BD Solar

REFRIGERATION AND
AIR CONDITIONING

CONTENTS

BD COMPRESSORS
SOLAR

1. 0 INTRODUCTION

The introduction of this document is dedicated to Danfoss customers, designers, consultants and others who want to gather information how to start design/ build a solar powered refrigeration system using Danfoss BD compressors. Systems in question are limited to smaller systems where the BD compressors are applicable.

The document should not be seen as a final document claiming to contain all information regarding solar powered refrigeration systems. Danfoss is in a continuous process to develop and improve the products offered within solar applications.
The document will try to keep the focus on the compressor and electronic unit, where Danfoss has its core competence.

The document should not be seen as a guideline to design an optimized solar refrigeration system. In the design of the other system components Danfoss will recommend customers to seek information at the different manufactures of these components.

2 .0 APPLICATIONS

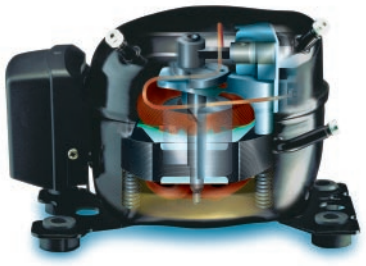
The applications suitable for solar powering are basically not limited compared to a normal 12/24 V d.c. battery powered system. Limitations are normally given through:

- *Cost*
  Solar are 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 become to long the voltage drop becomes too large. If this has to be compensated through a bigger square of the wires this could be a cost issue as well.

Some applications suitable for solar are listed here below.

- Refrigerators
- Freezers
- Vaccine coolers
- Ice crème freezers
- Bottle coolers

	Refrigerator +32°C ambient	Freezers +32°C ambient
BD 35F, R134a	Up to 200 liters	Up to 100 liters
BD 35K, R600a		
BD 50F, R134a		
BD 100CN, R290		
BD 120CN, R 290		



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

WHO specifications

A very suitable solar application is vaccine coolers. A lot of these cooler are built to meet the WHO specifications.

The demands and test procedures can be found on WHO´s web page www.who.org, under "Equipment performances specifications and test procedures", under "E3 – Refrigerators and freezers". Here are several categories such as the category "Solar (PV) refrigerator/icepack freezer".

Some important demands are:
At ambient +32°C the following must be fulfilled:

- Vaccine temperature must be stored within +0 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 liters.

3 .0 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

Compressors

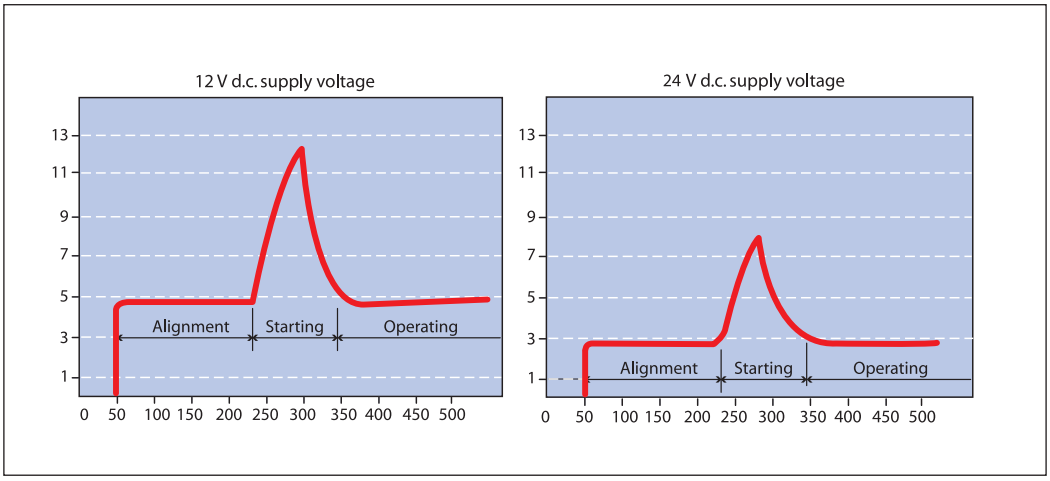
Starting current

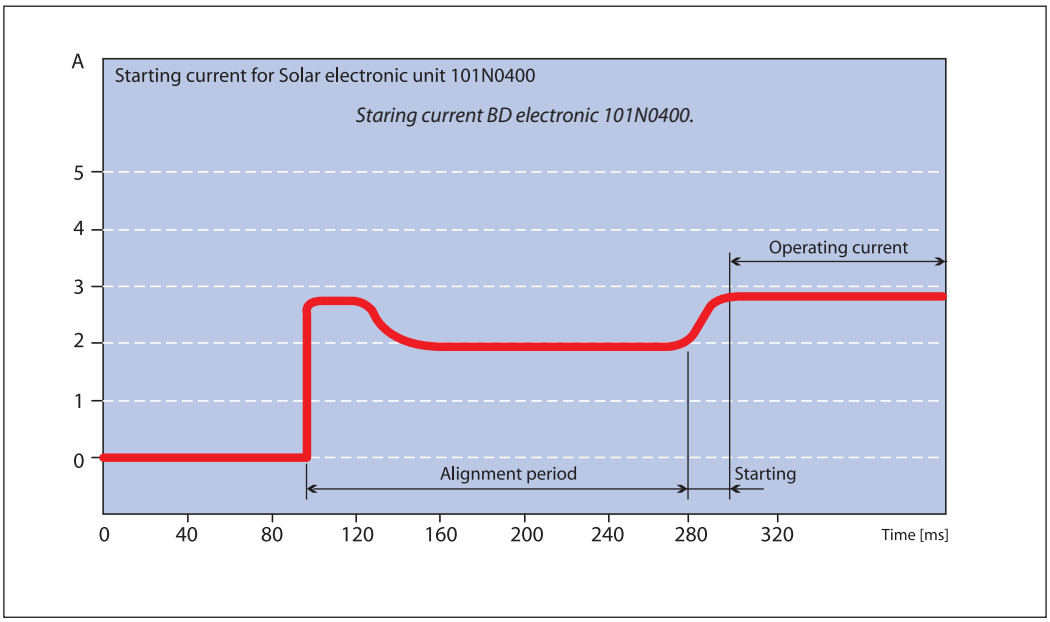
! The starting current depend on the system you choose, direct solar cell driven with eutectic plates or a battery assisted system.

Direct solar opperated system.
The starting current of the compressor is important to know as it is important for selection and sizing of the solar panel.
Danfoss offers a dedicated solar electronic with a built in soft start function that reduces the starting current not to be bigger than the operating current. See curve below.
This means that the selection / sizing of the panel have to be done based on the cooling demand. However Danfoss is recommending a 120 W solar panel. The power consumption of the compressor can be found in the datasheet. The code no for this dedicated electronic unit is 101N0400.

Battery assisted system
In a battery assisted system a standard elecronic unit 101N0210 or 101N0300 should be used as the starting current is not an important issue.

Starting current for standard electronic 101N0210 and 101N0300





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

Adjustment of capacity

The Danfoss electronic unit 101N0400 and 101N0300 has a built in function called Adaptive Energy Optimization (AEO). The function is automatically adjusting the speed and thereby the capacity of the compressor. The capacity is adjusted so that the thermostat runtime is approx. 30 minutes.
Alternatively the speed/capacity can be adjusted manually. This is done by means of a resistor in the thermostat circuit. Please refer to the instruction for selection of resistor.
If the system is designed with an ice banc, it will be preferable to run maximum capacity all time sun power is available. In that case the speed should manually be keep at maximum 3500 rpm.

4.0 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 Danfoss 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 power-supply. Typically a panel betweeen 40-80 W is recommend.

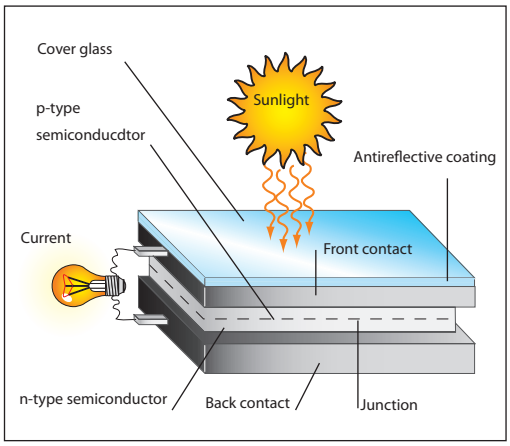
Price wise a rule of thumb says $US 4-5 per watt. The figure may differ between brands and countries and quantities bought.

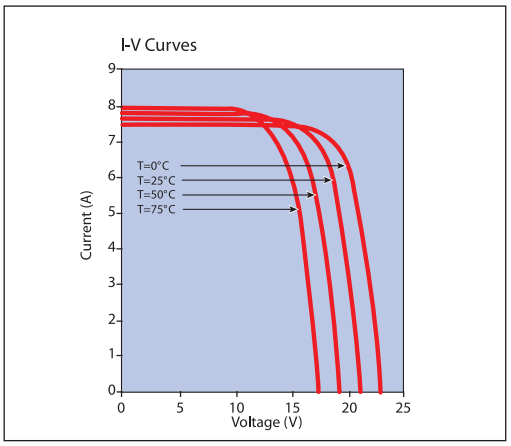
The current and power outputs of PV modules are approx. proportional to sunlight intensity. At a given intensity, a module's output current and operating voltage is determined by the characteristics of the load. If that load is a battery, the battery's internal resistance will dictate the module's operating 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 × 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 point (voltage/current combinations) at a given cell temperature and light intensity. Increase in cell temperature increases current slightly, but drastically decrease in voltage.

Maximum power is derived at the knee of the curve.





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

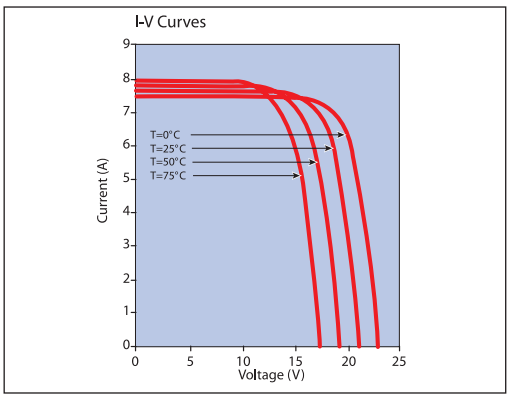
**Example of specifications from a PV manufactures catalogue (2003)*

Capacity vs size

As a rule of thumb the size of a 150 W panel is 1 m^2, 75 W panel 0.5 m^2 etc.

Voltage

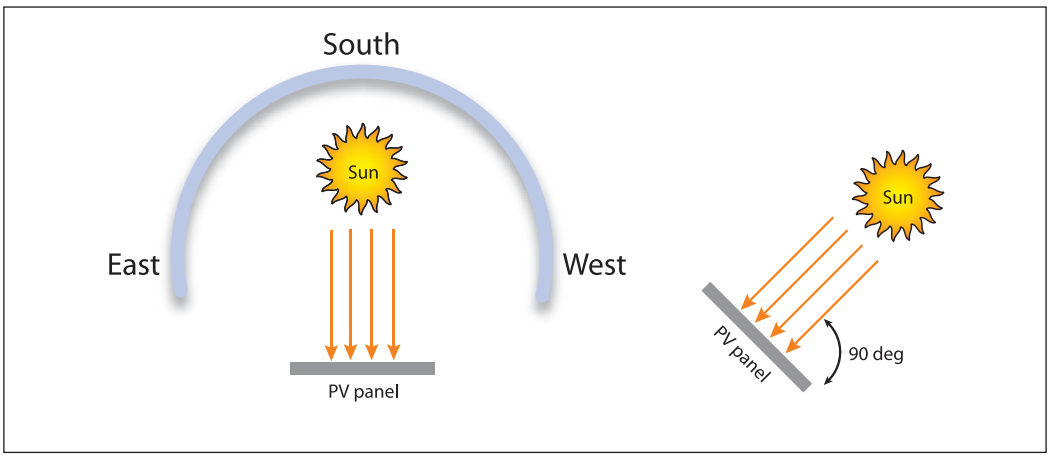
The Danfoss BD compressors can handle a voltage range between 10 and 45 V d.c., using the dedicated solar electronic, code no 101N0400.
Using the standard electronic units 101N0210, 1001N0300N or 101N0500 a 220 kΩ resistor must be mounted between terminal C and P. The voltage range will then be from 9.6 to 31.5 V d.c.
All PV manufactures offer datasheets containing I-V curves. These IV curves show the relation between Voltage and Amperes. See example below.
At no load on the panel the voltage is relative high compared to the voltage at a loaded panel.



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.

Below pictures showing how to orientate the panels in the northern hemisphere.



Northern hemisphere

Manufactures

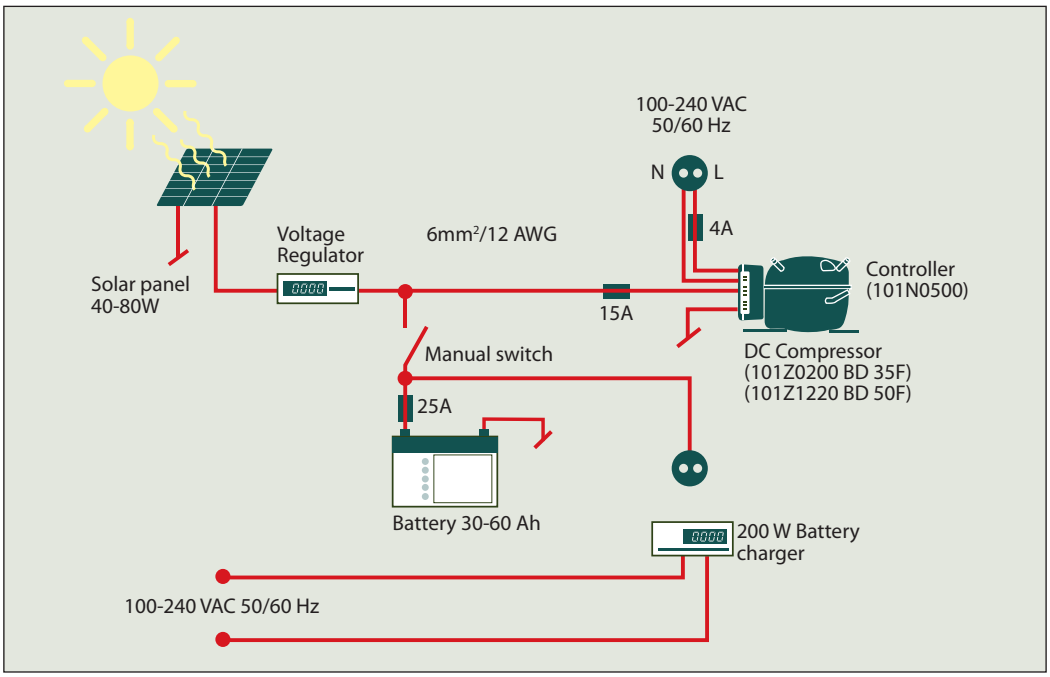
On the market there is a huge amount of solar-panel manufactures. Using a search engine on the web will bring you a lot of manufactures.
Danfoss does not have a preference for a particular brand or manufacture.

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

Company	**Country**	**Web page**
Sharp	Japan	www.sharp-world.com
BP Solar	UK	www.bpsolar.com
Kyocera	Japan	www.kyocerasolar.com
Shell Solar	Holland	www.shallsolar.com
RWE Solar	USA	www.asepv.com
Isofoton	Spain	www.isofoton.com
Sanyo	Japan	www.sanyo.com/industrial/solar
Mitsubishi	Japan	www.mhi.co.jp/power/e_a-si/index
Photowatt	France	http://www.photowatt.com

5.0 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 looked at.
It is recommended to use solarbatteries or deep cycle batteries.

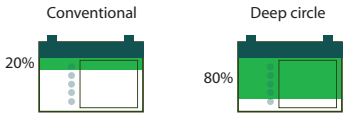


Lead-Acid Batteries

Lead
Lead-acid batteries are the most common in PV systems because their initial cost is lower and because they are readily available nearly everywhere in the world. There are many different sizes and designs of lead-acid batteries, but the most important designation 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 a permanent loss of capacity.

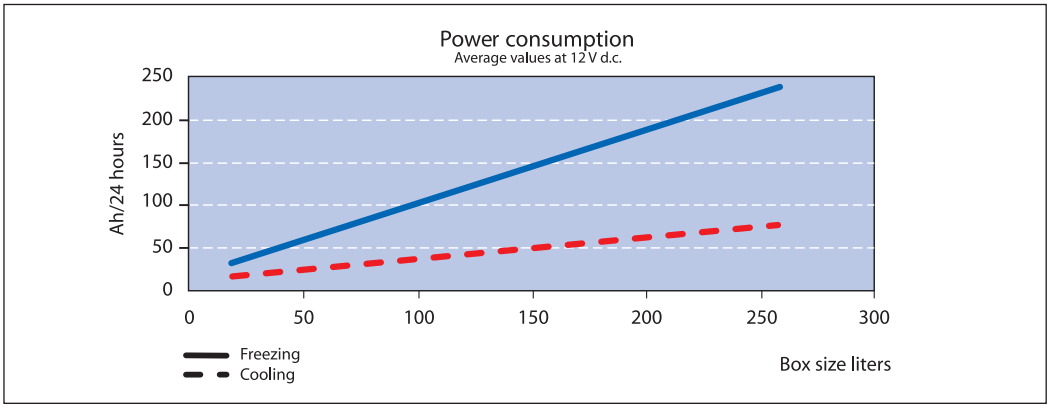


Sealed deep-cycle lead-acid batteries

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 how to size the battery is shown in the graphs below.

The curves are on a guideline, and the consumption may vary depending on ambient temperature, insulation of the appliance etc.



BD 35F 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 a lot of things.
Some of them are:

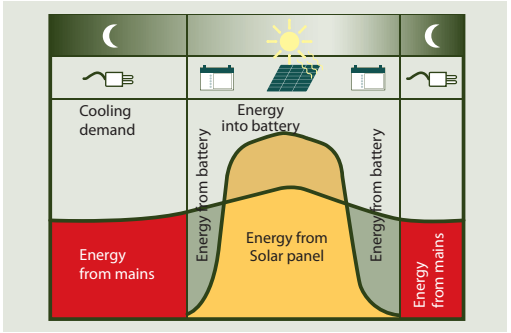
- Load on the system
- Insulation of the cabinet
- Size of the cabinet
- Ambient temperature
- Evaporating temperature
- Condensing temperature

For the battery the factors that matters how fast it is drained are:

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

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

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



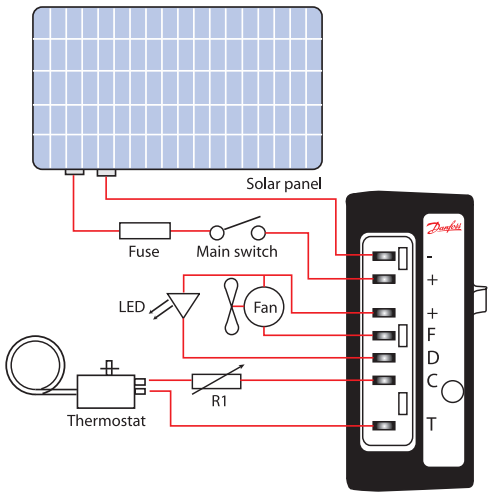
6.0
ICE PACK SYSTEM

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

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.

Refrigeration Circuit with icepacks

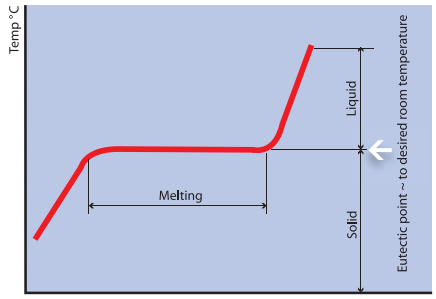


The main difference between 101N0400 and the standard electronic 101N0210 and 101N0300 is:
- Terminal P has been removed.
- Voltage range 10 to 45 V d.c.
- No load dump protection
- Starting current reduced
- Can start and operate on a solar panel down to 70 W (120 W recommended).

Example

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.

Example how to size the icepack

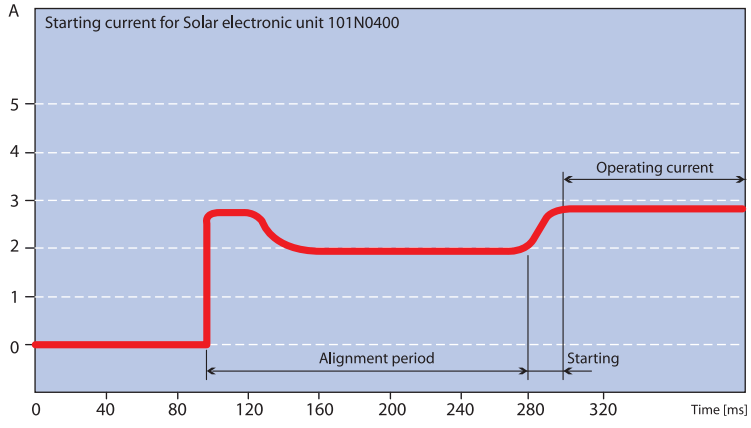


Box
150 L box ~ 50 Ah/24 h
50 AH ~ 2.1 Ah/h
2.1 A X 12V = 25.2 W average/24 h
25.2 X 24 ~ 605 W/24 h

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

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

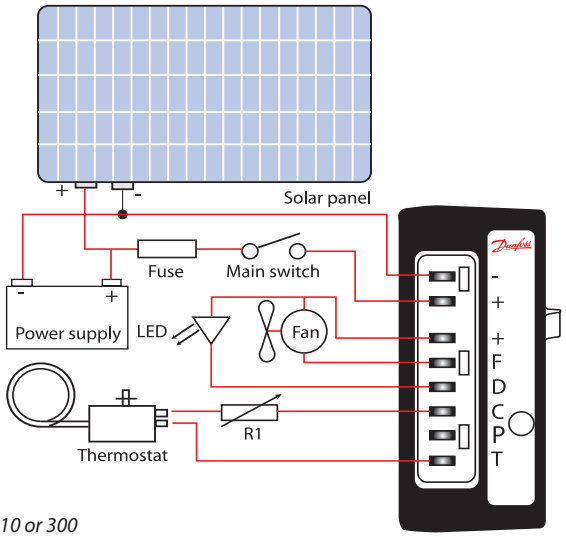
Icepacks
605-201 = 404 W ~ 404/93 ~ 5 kg ice ~ 16 hours without comp. operation



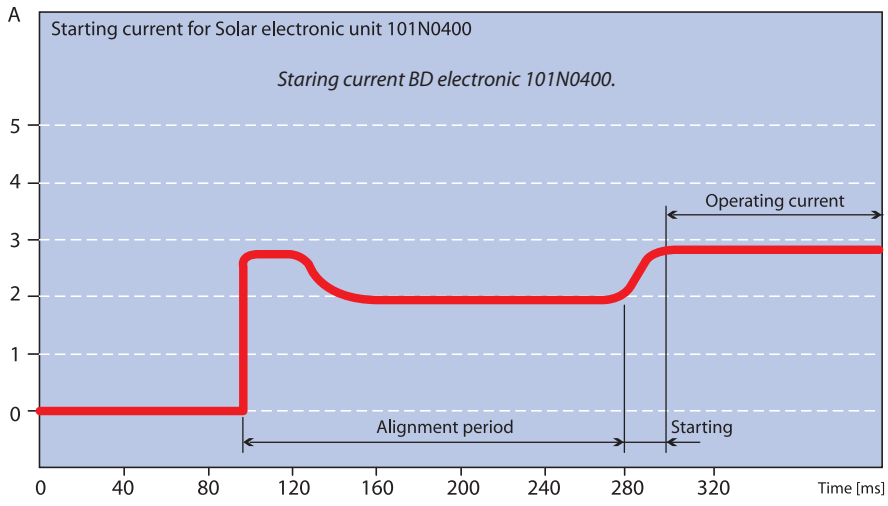
Example

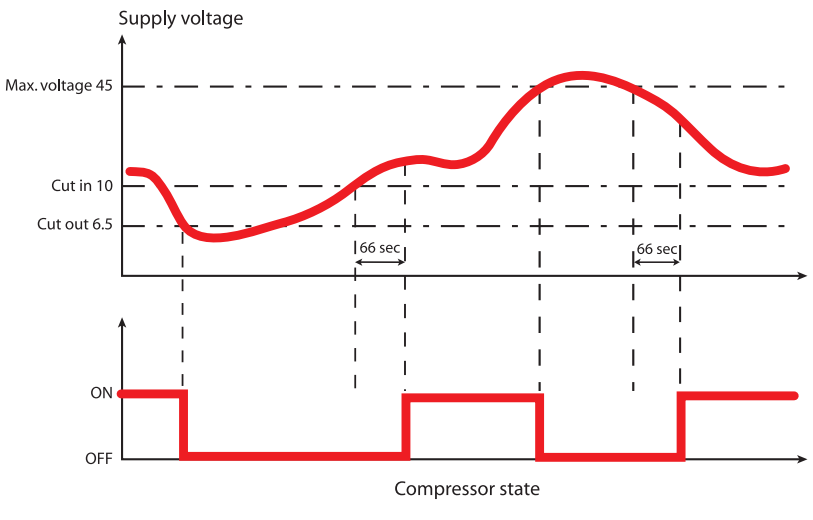
Solar

Refrigeration system
with battery backup



Standard electronic unit 210 or 300





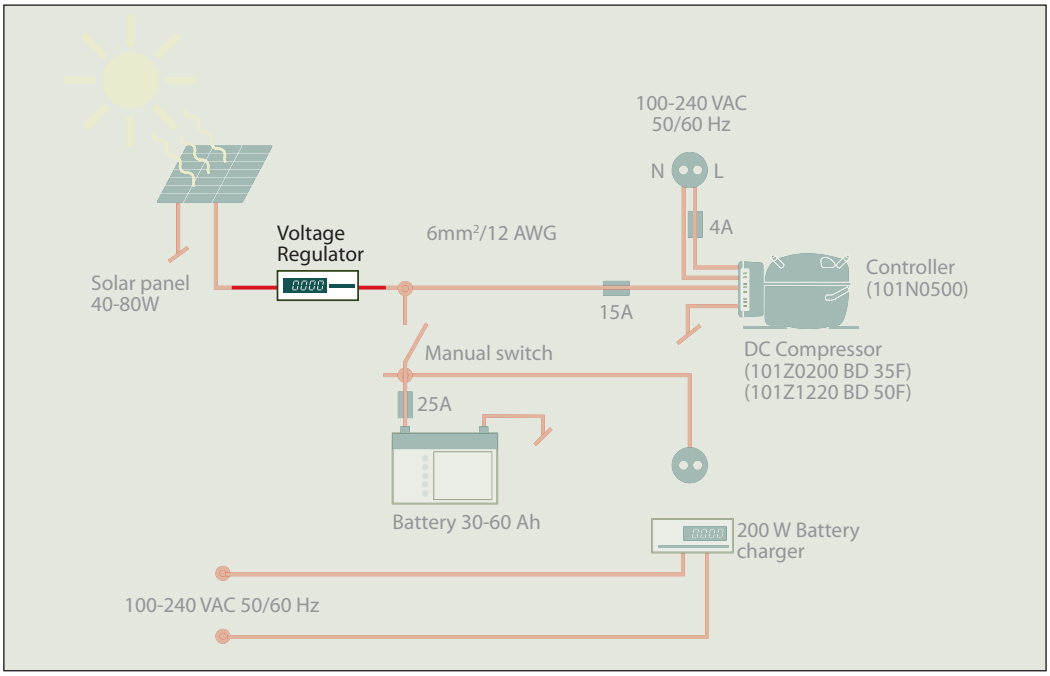
7.0 THERMOSTAT

The thermostat in a solar system can be a mechanical or electronic thermostat.
If a system with battery a power back up is used, it should be considered not to have a too small difference on the thermostat. 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 to high. The set point should be so low that the eutectic point of the ice packs is reached.

8.0 VOLTAGE REGULATOR/ POWER TRACKER

In order to utilize the full power from a PU panel it is recommended to mount or voltage regulator or power-tracker



9.0 PERFORMANCE DATA

R134a BD35F 10-45 V DC

Capacity (CECOMAF) **Watt**

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	16	24	27	33	44	57	72	90	111	136
2,500	20	30	34	41	55	71	90	112	139	
3,000	23	32	36	45	62	82	105	133		
3,500	26	36	40	51	70	94	122			

Power consumption **Watt**

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	18	23	25	29	34	38	43	48	53	59
2,500	23	31	33	38	441	50	56	62	69	
3,000	30	36	38	43	51	59	67	75		
3,500	36	43	45	51	60	69	79			

Current consumption (for 24 V applications the figures must be halved)

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	1.5	2.0	2.1	2.4	2.8	3.2	3.6	4.0	4.5	5.0
2,500	1.9	2.6	2.8	3.2	3.7	4.2	4.7	5.2	5.8	
3,000	2.5	3.0	3.2	3.6	4.2	4.9	5.6	6.2		
3,500	3.0	3.6	3.8	4.3	5.0	5.7	6.5			

R600a BD35K ** 10-45 V DC

Capacity (CECOMAF) — Watt

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	13.2	21.0	23.8	29.7	39.6	51.0	64.0	79.1	96.3*	116*
2,500	16.8	25.5	28.8	35.6	47.5	61.3	77.5	96.2*	118*	
3,000	20.7	30.5	34.3	42.3	56.3	72.9	92.4*	115*		
3,500	24.9	36.0	40.2	49.3	65.1	83.8*	106*			

Power consumption — Watt

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	18.5	22.5	23.9	26.4	30.3	34.2	38.0	41.8	45.7*	49.6*
2,500	23.8	28.5	30.0	32.9	37.2	41.5	45.8	50.2*	54.9*	
3,000	29.5	35.9	38.0	41.8	47.4	52.9	58.6*	64.6*		
3,500	35.1	42.7	45.2	49.7	56.4	63.0*	10669.7			

Current consumption (for 24 V applications the figures must be halved) — Amp.

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	1.54	1.88	1.99	2.20	2.53	2.85	3.17	3.48	3.81*	4.13*
2,500	1.98	2.37	2.50	2.75	3.10	3.46	3.82	4.19*	4.58*	
3,000	2.46	2.99	3.16	3.48	3.95	4.41	4.88*	5.38*		
3,500	2.93	3.56	3.76	4.15	4.70	5.25*	5.81*			

* Fan cooling of electronic unit compulsory
** For stationary use only

R134a BD50F

Capacity (CECOMAF) — Watt

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	20.1	31.0	34.9	42.8	56.3	72.2	91.6	115	144*	178*
2,500	27.0	39.0	43.4	52.7	68.9	88.9	113	144*	181*	
3,000	31.0	45.4	50.6	61.5	80.7	104	134*	171*		
3,500	38.1	53.2	59.1	71.9	95.0	124*	159*			

Power consumption — Watt

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	25.1	31.8	34.0	38.2	44.7	51.3	58.3	65.8	74.2*	83.5*
2,500	34.1	40.5	42.9	47.8	55.8	64.7	74.3	84.8*	96.1*	
3,000	39.9	49.2	52.2	57.8	66.5	76.4	88.4*	104*		
3,500	50.2	59.3	62.5	69.0	80.2	93.4	109*			

Current consumption (for 24 V applications the figures must be halved) — Amp.

rpm \ °C	-30	-25	-23.3	-20	-15	-10	-5	0	5	10
2,000	2.2	2.6	2.8	3.1	3.8	4.4	5.1	5.8	6.4*	6.9*
2,500	2.9	3.4	3.6	4.0	4.7	5.4	6.2	7.0*	7.8*	
3,000	3.5	4.2	4.4	4.9	5.6	6.5	7.4*	8.5*		
3,500	4.2	4.9	5.2	5.8	6.7	7.8*	9.0*			

R290 BD100CN

Capacity (CECOMAF) — Watt

rpm \ °C	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0
2,500	39.2	51.4	66.4	84.5	91.4	106	132	161		
3,100	46.6	62.8	82.1	105	114	132	163	200		
3,800	54.8	74.6	98.0	125	136	158	195	238		
4,400	60.5	82.3	108	138	149	173	214	261		

Power consumption — Watt

rpm \ °C	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0
2,500	46.3	51.6	58.1	65.5	68.1	73.2	80.8	88.0		
3,100	54.7	63.7	73.4	83.5	86.9	93.5	103	113		
3,800	63.3	76.2	89.1	102	106	115	127	138		
4,400	72.6	88.4	104	120	125	135	150	164		

Current consumption (for 24 V applications the figures must be halved) — Amp.

rpm \ °C	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0
2,500	3.86	4.30	4.85	5.46	5.68	6.10	6.74	7.33		
3,100	4.56	5.31	6.12	6.96	7.24	7.79	8.61	9.38		
3,800	5.27	6.35	7.43	8.50	8.86	9.55	10.56	11.51		
4,400	6.05	7.36	8.69	10.00	10.44	11.28	12.52	13.69		

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PERFORMANCE DATA

R290 BD120CN

Capacity (CECOMAF)

Watt

rpm \ °C	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0
2,500	30.6	40.2	51.9	66.0	71.4	82.9	103	126		
3,100	36.0	49.0	64.6	83.0	90.0	105	130	160		
3,800	40.5	56.6	75.6	98.0	106	124	154	189		
4,400	44.6	62.4	83.4	108	117	137	170	209		

Power consumption

Watt

rpm \ °C	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0
2,500	35.7	39.8	44.8	50.5	52.5	56.4	62.3	67.8		
3,100	41.9	48.9	56.3	64.0	66.7	71.8	79.4	86.5		
3,800	48.7	58.6	68.6	78.5	81.8	88.1	97.5	106		
4,400	57.4	69.1	80.8	92.5	96.4	104	115	125		

Current consumption (for 24 V applications the figures must be halved)

Amp.

rpm \ °C	-40	-35	-30	-25	-23.3	-20	-15	-10	-5	0
2,500	2.97	3.32	3.74	4.21	4.38	4.70	5.19	5.65		
3,100	3.49	4.07	4.69	5.34	5.56	5.98	6.61	7.20		
3,800	4.06	4.88	5.71	6.54	6.82	7.35	8.12	8.86		
4,400	4.78	5.76	6.74	7.71	8.04	8.66	9.58	10.44		




For further information please visit:
compressors.danfoss.com

Danfoss Compressors GmbH
Mads-Clausen-Strasse 7
P.O.Box 1443, D-24939 Flensburg
Tel: +49 461 4941-0
Fax: +49 461 44715

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