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Danfoss Compressors
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

<table>
<thead>
<tr>
<th>Refrigerator +32°C ambient</th>
<th>Freezers +32°C ambient</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD 35F, R134a</td>
<td>Up to 200 liters</td>
</tr>
<tr>
<td>BD 35K, R600a</td>
<td>Up to 100 liters</td>
</tr>
<tr>
<td>BD 50F, R134a</td>
<td></td>
</tr>
<tr>
<td>BD 100CN, R290</td>
<td></td>
</tr>
<tr>
<td>BD 120CN, R 290</td>
<td></td>
</tr>
</tbody>
</table>

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

Direct solar operated 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 electronic unit 101N0210 or 101N0300 should be used as the starting current is not an important issue.

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.
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 often depends on aestetics and how big a contribution is wanted from the PV panel of the total powersupply. Typically a panel between 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 \(\times\) 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.

**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 k\(\Omega\) 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.

![Orientation of the panels diagram](image)

### 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.

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Web page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp</td>
<td>Japan</td>
<td><a href="http://www.sharp-world.com">www.sharp-world.com</a></td>
</tr>
<tr>
<td>BP Solar</td>
<td>UK</td>
<td><a href="http://www.bpsolar.com">www.bpsolar.com</a></td>
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<tr>
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<td><a href="http://www.asepv.com">www.asepv.com</a></td>
</tr>
<tr>
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<td>Photowatt</td>
<td>France</td>
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</tr>
</tbody>
</table>

### 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 solar batteries or deep cycle batteries.

![Battery assisted system diagram](image)
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.

### 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.

### Lead-Acid Batteries

**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.

**Conventional**

**Deep cycle**

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.
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).

Refrigeration Circuit with icepacks

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

Example

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

Example how to size the icepack

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 $H_2O \sim 92.9\text{ Wh} \sim 30\text{ W}$ cooling capacity for 3 hours.

**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.

**Box**

- 150 L box $\sim 50\text{ Ah}/24\text{ h}$
- $50\text{ Ah} \sim 2.1\text{ Ah/h}$
- $2.1\text{ A} \times 12\text{ V} = 25.2\text{ W average}/24\text{ h}$
- $25.2\text{ A} \times 24 \sim 605\text{ W}/24\text{ h}$

**Compressor BD35F**

- Power consumption compressor $60\text{ W}$
- $ED \sim 605/60 \sim 10.1\text{ H} \sim 42\%$

**Solar panel**

- Contributes 8 hours/24 h $\sim 605 \times 0.33 = 201\text{ W}$

**Icepacks**

- $605 - 201 = 404\text{ W} \sim 404/93 \sim 5\text{ kg ice} \sim 16\text{ hours without comp. operation}$

**Example how to size the icepack**

- 1 kg $H_2O \sim 92.9\text{ Wh} \sim 30\text{ W}$ cooling capacity for 3 hours.
Solar

Refrigeration system with battery backup

Standard electronic unit 210 or 300

Example

Starting current for Solar electronic unit 101N0400

Staring current BD electronic 101N0400.

Supply voltage

Max. voltage 45
Cut in 10
Cut out 6.5
188 sec
68 sec
ON
OFF
Compressor state
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

<table>
<thead>
<tr>
<th>Capacity (CECOMAF)</th>
<th>Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm \ °C</td>
<td>-30</td>
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<tr>
<td>2,000</td>
<td>18</td>
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Power consumption

<table>
<thead>
<tr>
<th>Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm \ °C</td>
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<tr>
<td>2,000</td>
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<tr>
<td>2,500</td>
</tr>
<tr>
<td>3,000</td>
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<tr>
<td>3,500</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm \ °C</td>
</tr>
<tr>
<td>2,000</td>
</tr>
<tr>
<td>2,500</td>
</tr>
<tr>
<td>3,000</td>
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<tr>
<td>3,500</td>
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</table>
### 9.0 PERFORMANCE DATA

#### R600a BD35K ** 10-45 V DC

<table>
<thead>
<tr>
<th>Capacity (CECOMAF)</th>
<th>Watt</th>
</tr>
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<tbody>
<tr>
<td>R290 BD100CN</td>
<td></td>
</tr>
<tr>
<td>R134a BD50F</td>
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</tr>
</tbody>
</table>

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

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

#### Power consumption

- For connecting electronic and compressor

#### R134a BD50F

<table>
<thead>
<tr>
<th>Capacity (CECOMAF)</th>
<th>Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>R290 BD100CN</td>
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</tr>
<tr>
<td>R134a BD50F</td>
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</tbody>
</table>

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

- Fan cooling of electronic unit compulsory
- For stationary use only
### R290 BD120CN

#### Capacity (CECOMAF)

<table>
<thead>
<tr>
<th>°C</th>
<th>2500</th>
<th>3100</th>
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<th>4400</th>
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<td>25</td>
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<td>52.4</td>
<td>54.4</td>
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<td>22.4</td>
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<td>13.6</td>
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<td>40</td>
<td>5.6</td>
<td>6.2</td>
<td>6.8</td>
<td>7.4</td>
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#### Power consumption

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<th>3100</th>
<th>3800</th>
<th>4400</th>
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<td>5.4</td>
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#### Current consumption (for 24 V applications the figures must be halved)

<table>
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<tr>
<th>°C</th>
<th>2500</th>
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<tr>
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<td>.5</td>
<td>.6</td>
<td>.7</td>
</tr>
</tbody>
</table>

For further information please visit: [compressors.danfoss.com](http://compressors.danfoss.com)