

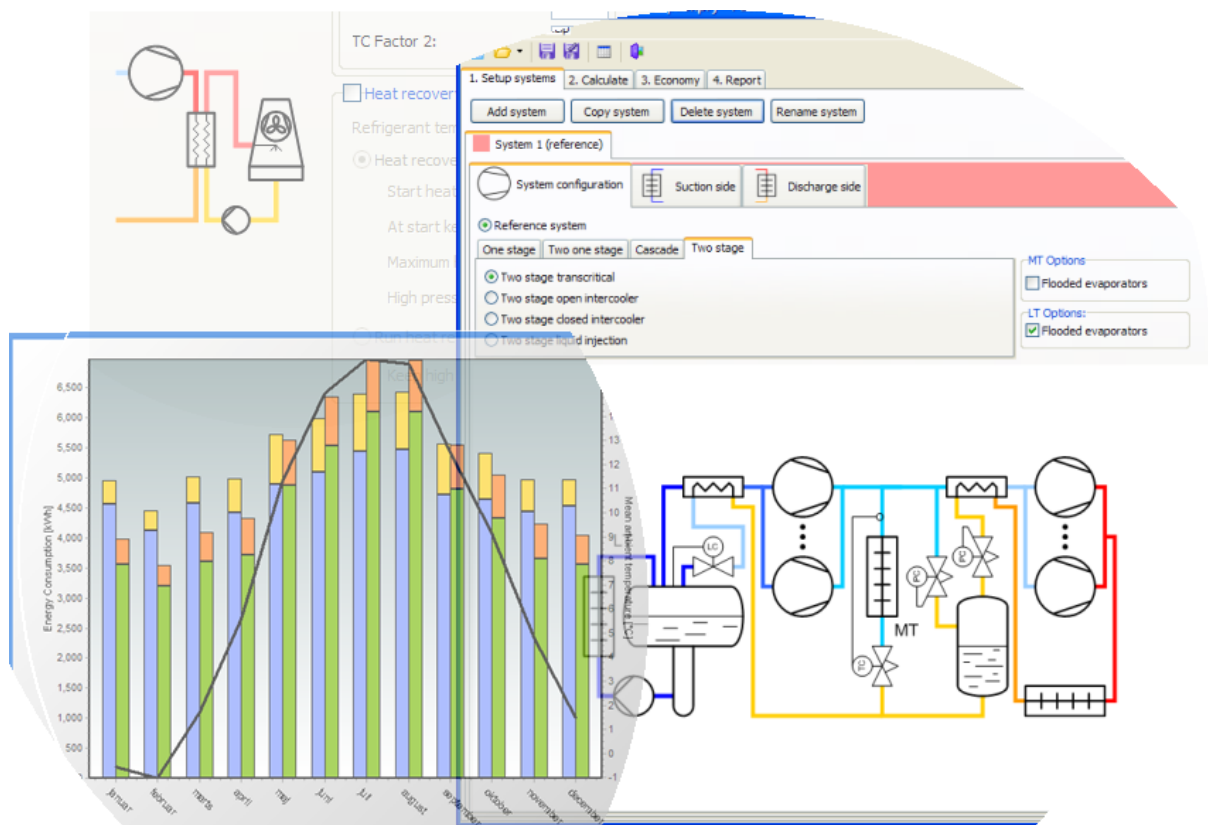
# Pack Calculation Pro



## User's guide

Version 5.3

IPU, December 2022



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## 2 Release notes

This section lists changes that may cause changes in simulation results compared to earlier versions of Pack Calculation Pro, and other changes worth being aware of.

### *V5.3 (December 2022)*

New system types:

- Two-stage transcritical ejector
- One-stage transcritical ejector, parallel compression
- Two-stage transcritical ejector, parallel compression

Other new functionality:

- Calculating rating points for each system, see chapter 10.
- Generic compressor feature, for rough estimate calculations. See chapter 6.1
- Dorin compressor update
- Bitzer compressor update
- Energy delivered (heating/cooling) now shown in Summary

Changed simulation results:

- Ground-source heat pumps – no longer possible to enter DT\_0 and Qe\_0
- Heat pump evaporator fans no longer assumed to run 100% the full hour when compressor only runs e.g., 50% of the time – now assumed they turn on and off in sync with compressors.
- Known Evaporator Size for refrigeration now auto dimensioned with DT of 10K instead of 5K.
- Fix liquid temperature calculation in closed intercooler and liquid injection cycles, which was calculated slightly wrong since v5.0
- Increase solving accuracy of liquid injection and two-one-stage common condenser capacity as function of Tc
- Restricted Free Cooling so it only can cover MT cooling in two-stage refrigeration systems.
- Improvements when comparing one-stage with two-stage refrigeration systems.

## V5.2 (March 2022)

New system types:

- One stage transcritical, ejector. See Appendix C.1.3
- Cascade heat pump, subcritical. See Section 7.2 and Appendix C.5.1

Other new functionality:

- Frascold: Added 511 new CX and SRC compressors for R134a, R290, R448A, R449A, R513A, R1234ze(E)
- Bitzer: Added 837 new 60 Hz compressors, 365 new 50 Hz compressors
- Improved scroll bar placement on Suction/Discharge side for small screens

Changed simulation results:

- Bitzer: Updated 472 existing 50 Hz compressors. CSH/CSW/HHK/HS/OHK/OS families.
- #193: Heat pump COP and COSP in plots corrected
  - COP for heat pumps in plots and export were before calculated from evaporator capacity, now based on delivered condenser capacity. The 'Average COP' in Summary now aligns well with the 'COSP' curve, at least for one-stage. For more details, see section 0.

## V5.1 (September 2021)

Changed simulation results:

- **#170: Cooling Tower issues**
  - Fixed crash and simulation stability issues with poorly dimensioned condenser
  - Fixed unit of **mWater** and **VAir** to **[kg/h]** and **[m3/h]** respectively, in plots and export. Until now, data was in [kg/s] and [m3/s], while nomenclature listed them in [kg/h] and [m3/h].

Low impact:

- **#169:** Warning about "too low capacity" unclear
  - Too low cooling capacity errors for two-stage transcritical systems were listing wrong required capacity, as LT contribution was omitted from that value
  - Not explicitly shown if warning came from LT or MT pack. Now shown explicitly

This also includes earlier fixes from v5.0.2 and v5.0.3 which got released in June 2021, especially fixing some regressions with simulating parallel compressor packs containing variable-speed compressors.

## V5.0 (April 2021)

### New functionality:

- New refrigerants available for simulation:
  - R32
  - R448A, R449A, R450A
    - Dew point evaporation temperatures only for now! No mid-point calculation
  - R513A
  - R1234yf, R1234ze(E)
- Automatic update check added.
  - No automatic download or installation – only notification – at this point.

### Changed functionality:

- Personal (limited version) usage now requires registration.
- Demo version introduced, which allows simulation with R22 only.

### Changed simulation results:

- Parallel compression and bypass valve can now operate simultaneously, making the calculation more accurate. See details in section 0.

## v4.6 (2020-06-17)

- **#126:** If transcritical system would have run subcritical just looking at ambient conditions, but is forced into transcritical by heat recovery, fan power consumption fell to zero, while it should have been 100%. Changed simulation results so fan + pump power consumption is 100%.
- **#133:** Gas cooler outlet temperature not limited when heat recovery active. Should have been limited to value from 'Discharge Side' > 'Subcritical control' > 'Minimum Tc'. Changed simulation results so Tc now also is limited to selected minimum when heat recovery is enabled.
- **#138:** When running the 64-bit version of Pack Calculation Pro, CO2 transcritical simulations were giving slightly different results from the 32-bit version. Fixed so 64-bit version gives same results as 32-bit version.
- **#139:** For "two-one-stage, common condenser" system, fan and pump power consumption in 'Summary' and 'Table' tables was not matching with plotted data or Excel export. Simulation results unchanged, but "Summary" and "Table" content (also in report) changed.
- **#140:** Transition zone between subcritical and transcritical behaving wrong, leading to jump in Tgo when switching from subcritical to transition. Changed simulation results so Tgo follows the expected transition from subcritical to transcritical, leading to lower compressor power consumption.

Changed functionality:

- Simulation results exported from Plots window are now exported with .csv extension, and always use dot (.) as decimal separator and comma (,) as thousands separator, which makes the file easier to use independent of your computer's settings, but gives some extra steps when importing in e.g., Excel. See new section **9.4.1**

*v4.4.6 (2019-11-19)*

Changed simulation results:

- **#125:** IWEC2 weather data files (marked with IW2 in location list, introduced in v4.4.4) were read 8 hours off



### 3 Introduction

Pack Calculation Pro is an application for calculating and comparing yearly energy consumption of refrigeration systems and heat pumps.

Among others, different system layouts, refrigerants and control strategies can be compared, including transcritical CO<sub>2</sub> systems with ejectors and/or parallel compressors. The systems are compared based on typical meteorological year (TMY) weather data for a geographical location.

Traditionally, refrigeration systems (and heat pumps) were dimensioned based on a single operating point, usually somewhere around the point where the load is highest. This approach ensures that the system will deliver the cooling (or heating) required, but also has some drawbacks:

- Performance in a single point does not say anything about the performance in other operating points – i.e., part load performance
- Performance points often leads to certain “standard” operating conditions at which components are rated – and compared. The problem is that most systems never, or very seldom, run at the “standard” operating conditions, which essentially means that most components are designed and optimized for conditions rarely seen in real life (most compressors will for example benefit from a lower, optimal, pressure ratio...)
- It is difficult to evaluate payback time of energy saving measures based on a full load operating condition... Often energy saving measures only show their value at part load conditions.

Various standards exist for calculating seasonal performance of refrigeration systems and heat pumps, such as SEER and SCOP. Common for these standards is that they rely on a handful of measurements / calculations at different loads, and some generalized climate conditions to extrapolate to a full year - as it is practically impossible to measure a real system in several different locations for different loads for a whole year.

These limitations are all addressed in Pack Calculation Pro:

- Performance of the systems is evaluated every hour of the year (= 8760 operating points)
- You get a clear overview of how well your system meets the demand (load profile) you define – but also get an overview of part load performance
- You can select weather data (TMY) from more than 3700 locations from all around the world
- You can compare systems under the same load and ambient conditions, evaluating the effect of energy saving measures
- You can compare energy consumption of the systems, but also make economic calculations - Payback time and Life Cycle Costs – and compare CO<sub>2</sub>e emissions (TEWI) for the different systems.
- Pack Calculation Pro contains models (based on manufacturer data) of more than 10000 commercially available compressors, ensuring you can model most systems, and equally important, get results for off-design operation based on detailed calculations.
- And of course, it's possible to calculate at specific rating conditions as well, when required in your project.

Moreover, you can create reports documenting the results of your calculations.

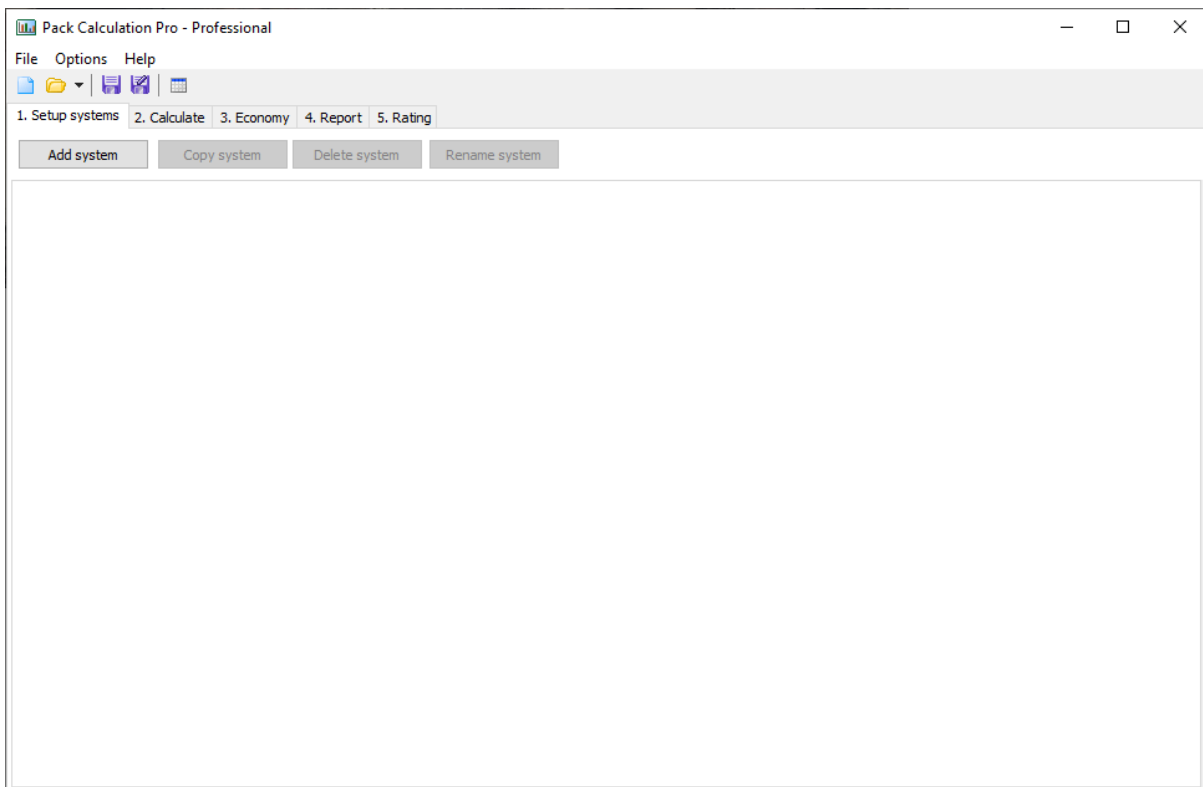
## 4 Getting started

The procedure for comparing systems in Pack Calculation Pro involves the following steps:

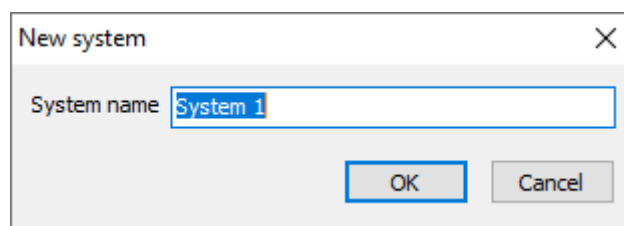
1. Setup systems – which involves selecting a systems layout for your refrigeration or heating system. For each system, you then define:
  - a. Compressor pack – either using generic compressors, or specific models from the database
  - b. Define suction side of the system (refrigeration load, evaporation temperature, etc.)
  - c. Define the discharge side of the system (heating load, condenser type, control, etc.)
  - d. Add groundwater cooling if applicable
2. Calculate energy consumption
3. Calculate Payback Time, Life Cycle Costs and CO<sub>2</sub>e emissions (TEWI)
4. Create a report documenting your findings

### 4.1 Setup systems

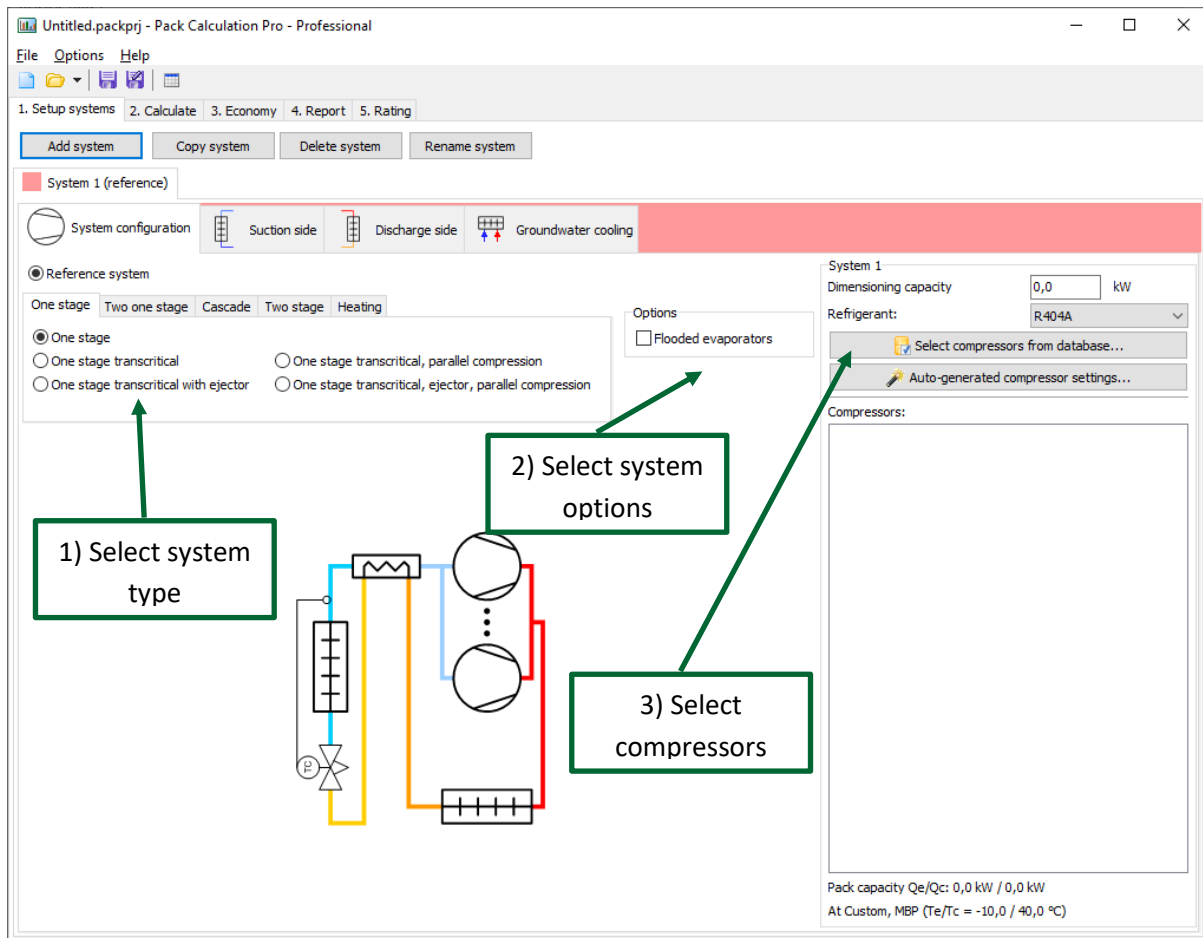
At start up, Pack Calculation Pro looks like:



To use the application, your first add a system by pressing the [Add system] button:



Enter a name of your choice and press [OK], and you should see the following screen:



The first system is automatically set as “Reference system”, i.e., the system any other systems are compared to.

On the first page of the system – the “System configuration” page – you go through the following three steps:

1. Select the desired system type
2. Select options – such as whether the evaporators are flooded or dry expansion (default)
3. Add compressing capacity to the selected system

For this example, we select a “Two stage transcritical” system, with flooded evaporators on the low stage:

The screenshot displays the Pack Calculation Pro - Professional software interface. The main window shows the system configuration for a two-stage transcritical system. The interface includes a menu bar (File, Options, Help), a toolbar, and a main workspace. The workspace is divided into a system configuration area on the left and a parameter input area on the right. The system configuration area shows a schematic diagram of the refrigeration system with two stages: LT (Low Temperature) and MT (Medium Temperature). The MT stage is highlighted in red. The parameter input area shows fields for dimensioning capacity, refrigerant (R744), and compressor selection buttons. Two green callout boxes with arrows point to the 'Select compressors from database...' buttons for the MT and LT stages, labeled 'MT Compressors' and 'LT Compressors' respectively.

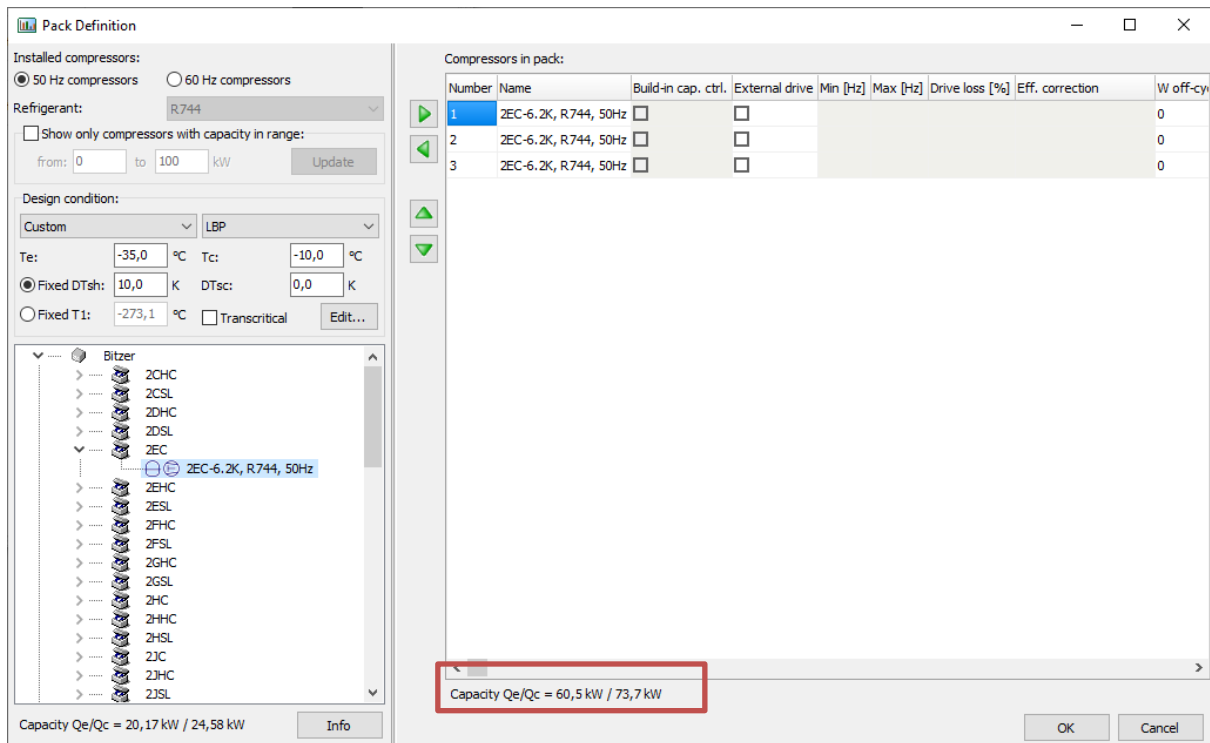
#### 4.1.1 Selecting compressors

The next step is to add compressors to the system. In this example we need to define compressors for both the low temperature (LT) and medium temperature (MT) stage.

For the sake of this example, we already know which compressors are used in our system.

Rest assured, if you do not know beforehand which compressors to use, it's also possible proceed with generic auto-generated compressors, see Chapter 6.1.

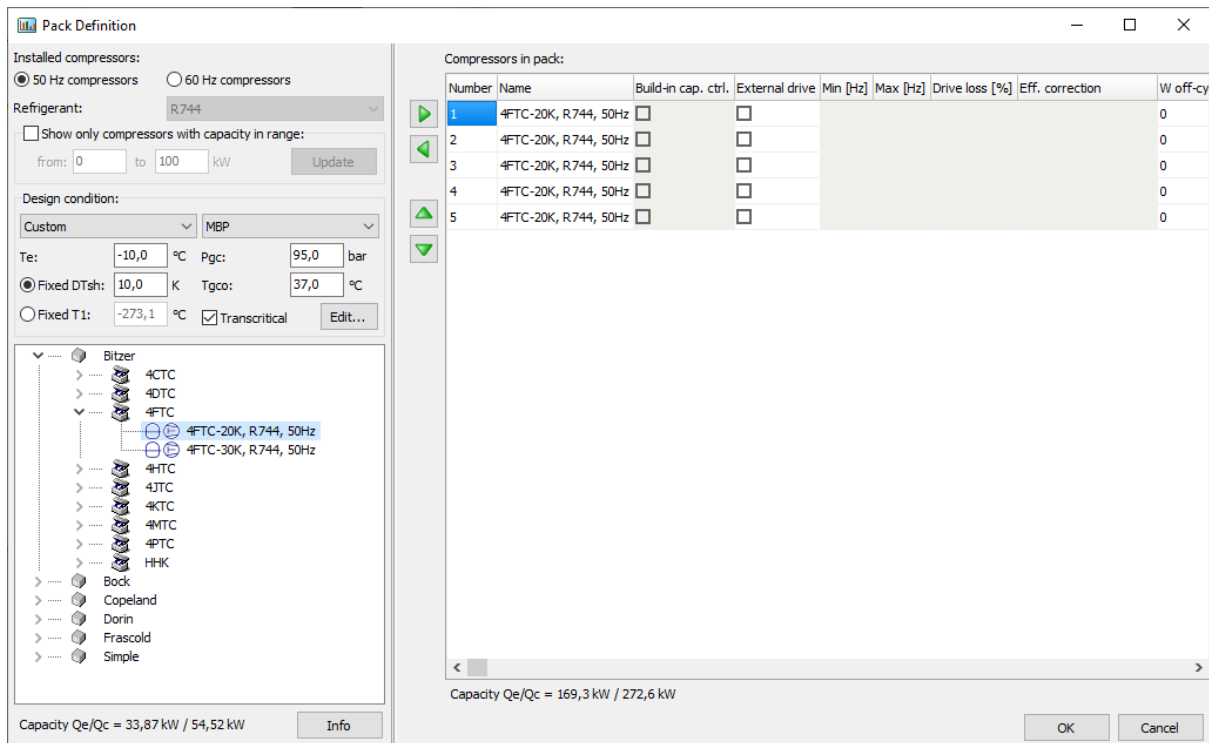
We start by selecting the LT compressors. Note that both the LT and MT compressors must be CO<sub>2</sub> compressors, as we selected a two stage transcritical system, and this implies CO<sub>2</sub> as refrigerant:



In the example we've selected 3 Bitzer compressors, which at an evaporation temperature of -35 °C and condensation temperature of -10 °C, has a cooling capacity of 60.5 kW and a condenser capacity of 73.7 kW. These numbers are important as they are used later!

The parameters/options you can define for each compressor are explained in chapter 6, for now, it's just important to note that you should select a design condition which is as close as possible to your expected running conditions. If you for example design a system for use in a supermarket in Dubai at medium temperature, and you select the design condition to  $T_e = -10$  °C and  $T_c = 25$  °C and you want 100 kW of cooling, you would probably end up with a too small system (as the condensation temperature much of the year will be above 25 °C, and then the capacity of the compressors will be lower than 100 kW).

When done press [OK] and you're back to the main screen. Then you select the MT compressors:



Note that here you are also limited (besides having CO<sub>2</sub> as refrigerant) to transcritical compressors. Also note that as the LT compressors had a dimensioning condenser capacity of 73.7 kW, the MT compressors only have 169.3 kW – 73.7 kW = 95.5 kW left for actual cooling at the medium temperature evaporators!

Also note that the MT compressors have a dimensioning condenser capacity of 272.6 kW. This number will be used when/if the size of the condenser is automatically selected.

When done press [OK] and the main screen should look like this:

createmannual.packproj - Pack Calculation Pro - Professional

File Options Help

1. Setup systems 2. Calculate 3. Economy 4. Report 5. Rating

Add system Copy system Delete system Rename system

Transcritical (reference)

System configuration Suction side Discharge side

Reference system

One stage Two one stage Cascade Two stage Heating

Two stage transcritical  
 Two stage transcritical, ejector  
 Two stage open intercooler  
 Two stage liquid injection  
 Two stage transcritical, parallel compression  
 Two stage transcritical, ejector, parallel compression  
 Two stage closed intercooler

MT Options

Flooded evaporators

LT Options:

Flooded evaporators

Transcritical, MT

Dimensioning capacity  kW

Refrigerant: R744

Select compressors from database...

Auto-generated compressor settings...

Compressors:

Bitzer 4FTC-20K  
 Bitzer 4FTC-20K  
 Bitzer 4FTC-20K  
 Bitzer 4FTC-20K

Pack capacity Qe/Qc: 169,3 kW / 272,6 kW

At Custom, MBP (Te/Pgc = -10,0 °C / 95,0 bar)

Transcritical, LT

Dimensioning capacity  kW

Refrigerant: R744

Select compressors from database...

Auto-generated compressor settings...

Compressors:

Bitzer 2EC-6,2K  
 Bitzer 2EC-6,2K  
 Bitzer 2EC-6,2K

Pack capacity Qe/Qc: 60,5 kW / 73,7 kW

At Custom, LBP (Te/Tc = -35,0 / -10,0 °C)

Again, note the capacity of the two compressor packs:

LT (Low Temperature) pack:

- Cooling capacity  $Q_e = 60.5 \text{ kW}$
- Condenser/heating capacity  $Q_c = 73.7 \text{ kW}$

MT (Medium Temperature) pack:

- Cooling capacity, total  $Q_e = 169.3 \text{ kW}$
- Cooling capacity for MT evaporators  $Q_{e, \text{evap}} = 169.3 \text{ kW} - 73.7 \text{ kW} = 95.6 \text{ kW}$
- Condenser/heating capacity  $Q_c = 272.6 \text{ kW}$

Now the compressor packs (and therefore the size) of your system are defined. The next step is to define the suction side.

### 4.1.2 Suction side

For the selected system we define the suction side of both the LT and the MT compressors:

The screenshot displays the configuration interface for two systems, System 1, MT and System 1, LT. The interface is divided into several sections for each system:

- System 1, MT:**
  - Cooling capacity:** Profile: Constant, Dimensioning capacity: 95,6 kW, Tamb at dimensioning capacity: 32,0 °C, Profile change with ambient temp.: 1,00 %/K, Profile doesn't change if ambient temperature gets below: 20,0 °C.
  - Dry expansion evaporators:** Total superheat: 20,0 K, Non-useful superheat: 10,0 K.
  - Evaporation temperature:** Profile: Constant, Temperature for constant profile: -10,0 °C.
  - Secondary circuit:** Secondary pump power: 1,000 kW, with options for Power proportional to capacity (selected) and Constant power.
  - Additional:** Internal heat exchanger efficiency: 0,00 [0-1], Intermediate pressure: -4,0 °C.
- System 1, LT:**
  - Cooling capacity:** Profile: Constant, Dimensioning capacity: 60,5 kW, Tamb at dimensioning capacity: 32,0 °C, Profile change with ambient temp.: 1,00 %/K, Profile doesn't change if ambient temperature gets below: 20,0 °C.
  - Flooded evaporators:** Forced circulation: checked, Nominal pump power: 0,100 kW, with options for Power proportional to capacity (selected) and Constant power.
  - Evaporation temperature:** Profile: Constant, Temperature for constant profile: -30,0 °C.
  - Secondary circuit:** Secondary pump power: 1,000 kW, with options for Power proportional to capacity (selected) and Constant power.
  - Additional:** Internal heat exchanger efficiency: 0,00 [0-1].

For both systems you should define the cooling capacity. Note that this is only done once – if you add more systems later, the cooling capacity for these systems will automatically be the same as for the reference system.

When you define the Cooling capacity, you have the following options:

- **Profile.** You can select between a set of predefined profiles from the drop-down list, or you can define your own profile by pressing the [Profile] button (see also chapter 7.1.1).
- **Dimensioning capacity.** This value defines the size of the selected profile (profiles are relative). The program automatically selects a value, which is equal to the dimensioning capacity of the selected compressors. For the LT compressors the dimensioning cooling capacity was 60.6 kW and for the MT compressors it was 169.3 kW (which when you subtract the dimensioning condenser capacity of the LT compressors amounts to 95.5 kW).
- **Tamb at... etc.** The last three parameters define how the selected profile varies with ambient temperature. You can press the [Help] button to see an explanation of how the parameters influence the cooling capacity. If you want a truly constant profile, with no variation with ambient temperature, you should set **Profile change with ambient temp.** to 0 %/K and **Profile doesn't change if... to a very low value (for example -100 °C).**

If your system has dry expansion evaporators, you should define the total and non-useful superheat. If the total superheat is 20 K and the non-useful is 10 K, it means that the superheat in the evaporator(s) is 10 K (useful superheat), and that the suction gas on its way from the evaporator(s) to the compressor is heated 10 K (non-useful superheat).



If your system has flooded evaporators, you should select whether the refrigerant is pumped through the evaporator - in which case you can specify the pump power, or if the flow is natural circulation (deselect Forced circulation), in which case there is no power consumption of the circulation system.

For both dry expansion and flooded systems, you have the option of specifying a secondary circuit which circulates a secondary refrigerant to the places where cooling is needed. You only specify the pumping power – the actual secondary coolant is not included in the calculation.

Regardless of the selected evaporator type, you should specify the evaporation temperature. Generally, a flooded evaporator should be able to run with a higher evaporation temperature than a dry expansion evaporator (it has no superheat zone), and for both types, adding a secondary circuit will require a lower evaporation temperature.

Depending on the system you have selected, you should specify the following additional values:

- **Internal heat exchanger efficiency.** The temperature efficiency of the internal heat exchanger (see appendix A). A value of 0 means no heat exchanger and a value of 1 means an ideal heat exchanger. Values from 0.3 to 0.5 should be reasonable (if the heat exchanger is present).
- **CO<sub>2</sub> pump power.** Only applicable for cascade CO<sub>2</sub> systems. Enables you to define power consumption of the CO<sub>2</sub> pump.
- **Intermediate pressure.** Only applicable for two stage systems. For “standard” two-stage systems it is the pressure in the intercooler, for CO<sub>2</sub> systems it is the pressure in the separator.
- **Cascade temperature diff.** Temperature difference between the two sides of the cascade heat exchanger in cascade systems. Note: In real systems, this temperature difference would vary with load, but in the model, it is fixed.
- **Intercooler heat exchanger efficiency.** Temperature efficiency of heat exchanger in intercooler for a two-stage cycle with closed intercooler. A value of 0.6 to 0.9 should be reasonable.

Note that all the values above will have default values selected by the program. These default values can be changed by selecting the Options | Preferences menu (see chapter 13).

### 4.1.3 Discharge side

For the selected system the specification of the discharge side looks like this:

You first select the condenser type, and depending on the type, you specify the condensation temperature control and the size of the condenser.

The control of the condensation temperature is common for all condenser types but is slightly different between subcritical and transcritical systems. For more information on this, see chapter 8.1.1 and 8.1.2.

The program uses the condensation temperature control algorithm you specify to calculate the power consumption of fans (and possibly pumps). If you for example specify that the condensation temperature should be equal to the ambient plus 10 K, then at an ambient temperature of 15 °C, the program will try to find the capacity (0 to 100%) of the fans at a condensation temperature of 25 °C.

If the condenser is too small (i.e., you cannot get a condensation temperature of 25 °C even at 100% fan capacity), the program will automatically raise the condensation temperature until the fan capacity is 100%.

Details of the condenser model(s) used in the program are explained in appendix B.

When you have selected the condenser control, you are ready to calculate. Note though that if you want, you can customize the size of your condenser – but before you do this, you should read the section about condenser models in appendix B. Also note that every aspect of the automatically sizing of the condensers can be changed in the Options|Preferences menu.

## 4.2 Calculation

At this point you are almost ready to calculate the system. First you should select the desired geographical location, and possibly an operation schedule for the system:

The screenshot shows a software window with four tabs: 'Conditions', 'Monthly energy consumption', 'Summary', and 'Plots'. The 'Conditions' tab is active. It contains the following settings:

- Reference year:** A dropdown menu showing 'Copenhagen DRY'.
- Adjust ambient temperature by adding:** A text input field with '0' and a unit selector 'K'.
- Schedule:**
  - Monthly schedule (select months):** A grid of checkboxes for each month (January to December), all of which are checked. To the right of each row are buttons labeled 'Q1', 'Q2', 'Q3', and 'Q4'.
  - Week schedule:** A section with a checkbox that is unchecked. Below it, a table shows operating days and times:

Operating:		From:	To:
<input checked="" type="checkbox"/> Monday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Tuesday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Wednesday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Thursday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Friday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Saturday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Sunday	<input checked="" type="checkbox"/> All day	08:00	18:00
  - Controlled by ambient temperature:** A checkbox that is unchecked. Below it, a text input field with '0' and a unit selector '°C'.

The location can be chosen from 703 different cities all over the world. Each location is represented by a dataset containing hourly values of temperature and relative humidity throughout the year.

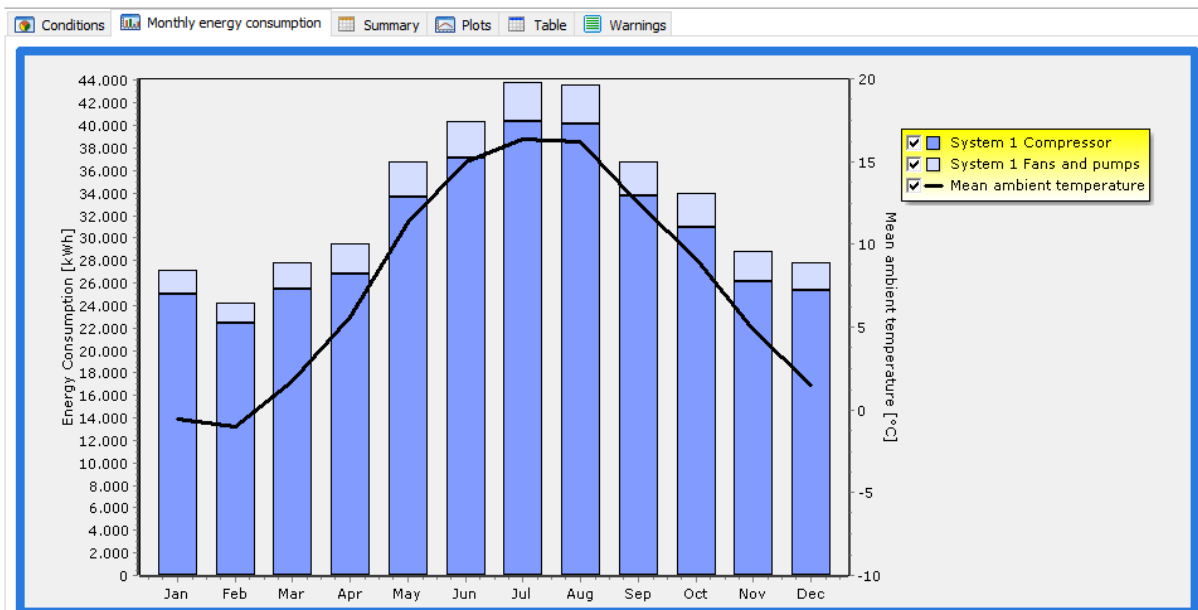
When you press Calculate, the program balances the refrigeration plant for each hour of the year and then represents the details in plots, diagrams, and tables.

The calculation is basically running according to the following scheme:

- In each hour, the ambient temperature, the load (from the load profile) and the evaporation temperature are known
- If the compressors are on/off controlled:
  - The program finds the minimum number of compressors that gives a cooling capacity larger than required to satisfy the load.

- The program finds the maximum number of compressors that gives a cooling capacity smaller than required to satisfy the load.
- The required load, the minimum and the maximum cooling capacity are used to calculate weight the results. If for example the required load is 10 kW, one compressor on gives 6 kW and two compressors 12 kW, then within the given hour, the compressor pack has been running with one compressor in 20 minutes and two compressors in 40 minutes. All results, including temperatures are scaled using this calculated weight.
- If the minimum cooling capacity is 0 (the load is satisfied with one compressor running on/off), then only energy consumption and capacities are scaled. Temperatures and pressures are not scaled (values from when the compressor is running are used).
- If the compressor is speed controlled:
  - The program finds the compressor capacity that gives exactly the required cooling capacity. If this capacity requires a speed less than the minimum speed of the speed-controlled compressor, the compressor is running on/off at the minimum speed.

The result of the calculation will look like this:



Showing the monthly energy consumption of compressors and condenser fans and pumps, if any.

Looking at the Summary tab, you'll see a table with a column for each system in the project:

Conditions		Monthly energy consumption		Summary	
		System 1 (reference)			
<b>Load fulfilment in % of time</b>					
LT:		100,0%			
MT:		100,0%			
Total:		100,0%			
<b>Load fulfilment in % of energy</b>					
LT:		100,0%			
MT:		100,0%			
Total:		100,0%			
<b>Energy delivered</b>					
LT [kWh]:		466.956			
MT [kWh]:		737.868			
Total [kWh]:		1.204.824			
<b>Average COP</b>					
LT [-]:		5,57			
MT [-]:		4,05			
Total [-]:		3,01			
<b>Pumps and fans energy consumption</b>					
LT [kWh]:		772			
MT [kWh]:		32.683			
Total [kWh]:		33.455			
<b>Compressor energy consumption</b>					
LT [kWh]:		83.098			
MT [kWh]:		283.935			
Total [kWh]:		367.033			
<b>Total energy consumption</b>					
LT [kWh]:		83.870			
MT [kWh]:		316.618			
Total [kWh]:		400.488			
<b>Savings</b>					
Yearly energy savings [kWh]:		-			
Yearly energy savings [%]:		-			

### 4.3 Adding another system

Looking at the results in the summary table, you get an idea of the yearly energy consumption of the selected system. You should note though that the absolute value of the energy consumption is very much depending on the conditions you enter – especially the load profile and the temperatures (both evaporation and ambient temperature). If you use the result of the simulation as an indication of the absolute energy consumption of a real system, you should be very careful defining both the load profile and temperature profiles!

On the other hand, if you add another system and compare the energy consumption between the two, the difference in percentage will probably be a much more realistic value – i.e., no matter what the absolute energy consumption of the two systems is, the difference in percent will be quite constant.

You can for example compare the existing CO<sub>2</sub> system with two one stage systems:

Press [Add System] and select a “Two one stage” system:

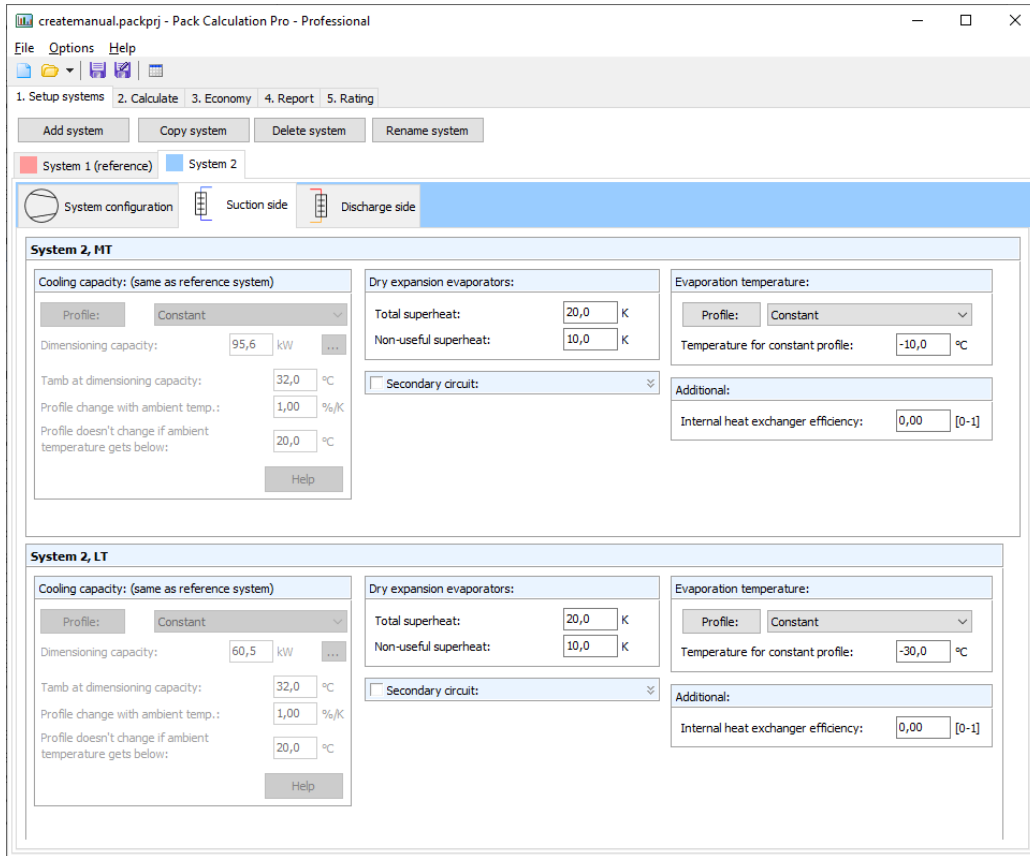
For now, we'll select compressors from database (other options will be covered in chapter 6), remembering that the dimensioning cooling capacity (to be comparable with the system 1) shall be about 60 kW on LT and 96 kW on MT:

The screenshot displays the 'Pack Calculation Pro - Professional' software interface. The main window is titled 'createmannual.packproj - Pack Calculation Pro - Professional'. The menu bar includes 'File', 'Options', and 'Help'. Below the menu bar, there are tabs for '1. Setup systems', '2. Calculate', '3. Economy', '4. Report', and '5. Rating'. A toolbar contains buttons for 'Add system', 'Copy system', 'Delete system', and 'Rename system'. The interface is divided into several sections:

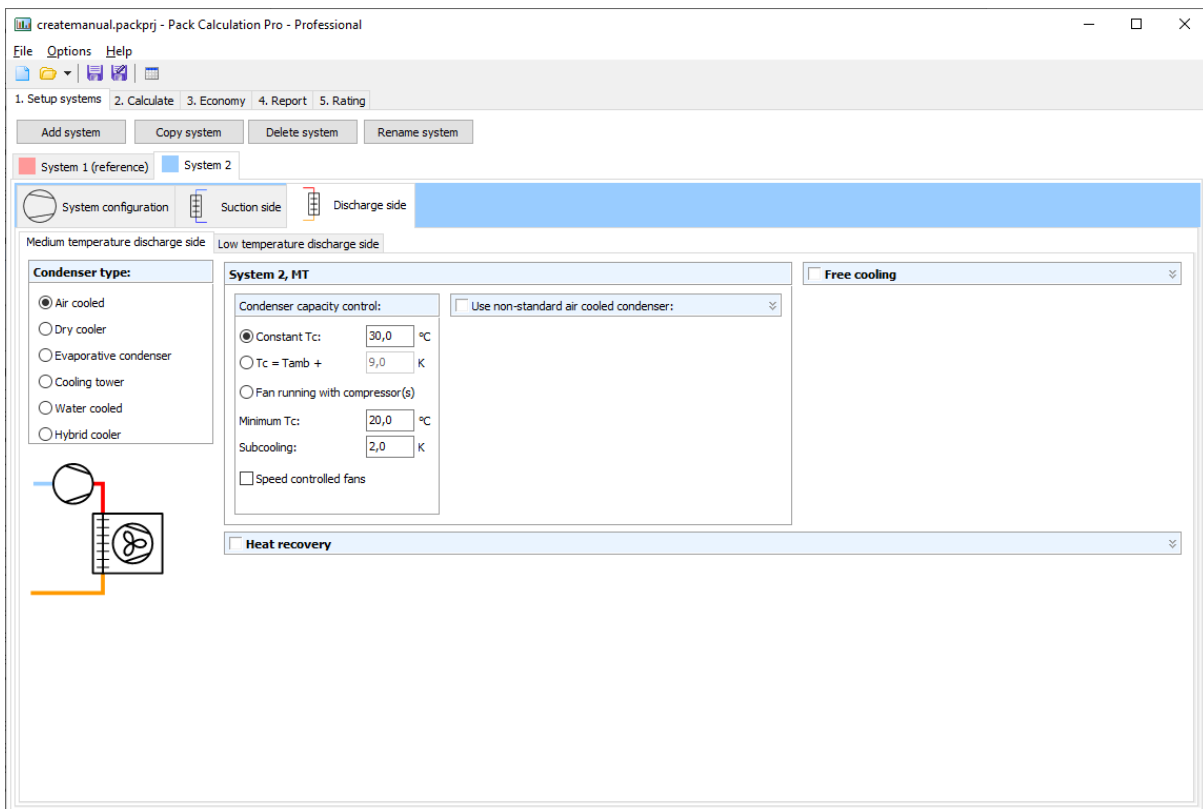
- System configuration:** Includes 'Suction side' and 'Discharge side' tabs. The 'Two one stage' option is selected.
- Reference system:** Includes 'One stage', 'Two one stage', 'Cascade', 'Two stage', and 'Heating' tabs. The 'Two one stage' option is selected, with sub-options for 'Two one stage' (selected) and 'Two one stage, common cond.'.
- MT Options:** Includes a checkbox for 'Flooded evaporators'.
- LT Options:** Includes a checkbox for 'Flooded evaporators'.
- Two one stage, MT:** Shows 'Dimensioning capacity' as 99,0 kW and 'Refrigerant' as R404A. It includes buttons for 'Select compressors from database...' and 'Auto-generated compressor settings...'. The 'Compressors' list shows two 'Bitzer 6J-22.2Y' units. Pack capacity is listed as 99,0 kW / 138,9 kW at Custom, MBP (Te/Tc = -10,0 / 40,0 °C).
- Two one stage, LT:** Shows 'Dimensioning capacity' as 63,3 kW and 'Refrigerant' as R404A. It includes buttons for 'Select compressors from database...' and 'Auto-generated compressor settings...'. The 'Compressors' list shows three 'Bitzer 6F-40.2Y' units. Pack capacity is listed as 63,3 kW / 113,0 kW at Custom, LBP (Te/Tc = -35,0 / 40,0 °C).

The central diagram shows a schematic of the refrigeration system with two stages (MT and LT), compressors, and evaporators.

The suction side of System 2 is much more limited, as the load profile is automatically set to be the same as for the reference system:

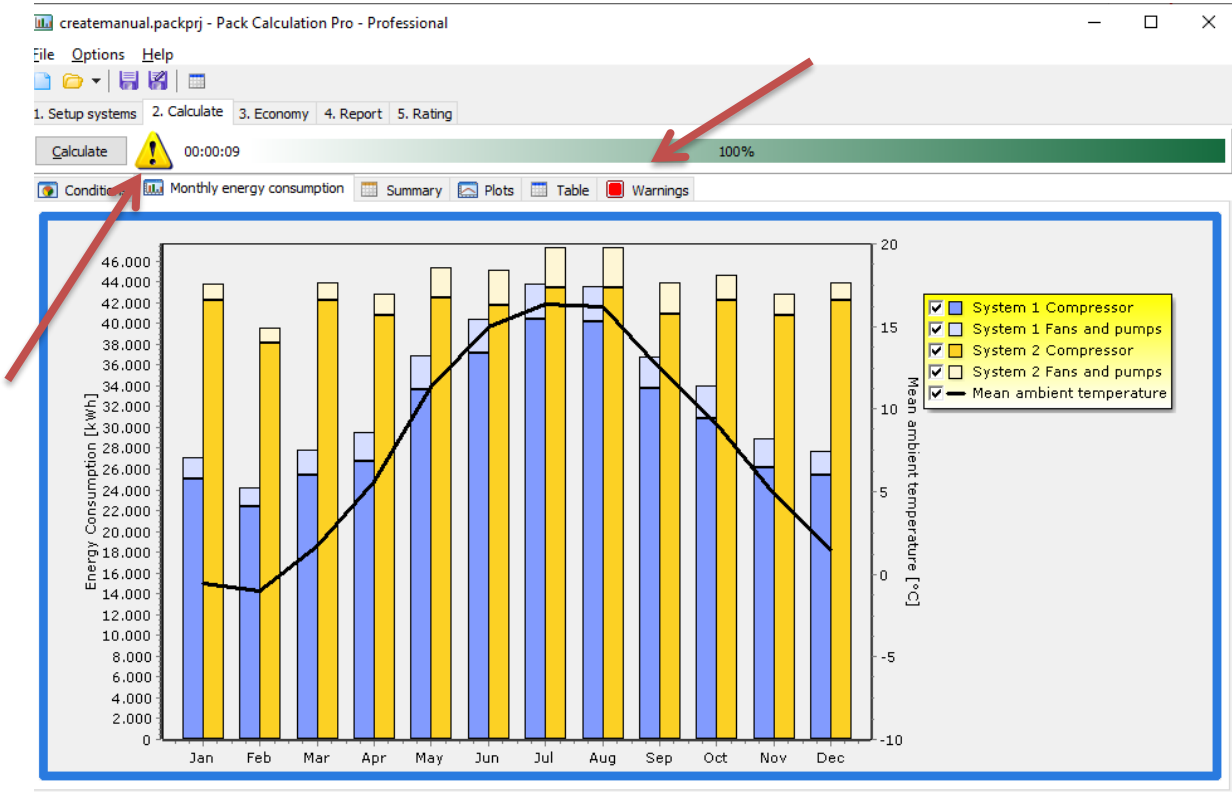


And for now, let the discharge side just be as default (note though that there are two discharge sides – one for each of the two one-stage systems):





Now we are ready to calculate again, and get the following result:



Note there is a warning sign beside the calculate button – if you open the Warnings tab, you'll see the warning occurs because System 2 cannot deliver the needed cooling in 3 hours on August 1<sup>st</sup>.

Looking again at the Summary page, you get an overview of the yearly difference between the two systems:

	System 1 (reference)	System 2
Load fulfilment in % of time		
LT:	100,0%	100,0%
MT:	100,0%	100,0%
Total:	100,0%	100,0%
Load fulfilment in % of energy		
LT:	100,0%	100,0%
MT:	100,0%	100,0%
Total:	100,0%	100,0%
Energy delivered		
LT [kWh]:	466.956	466.956
MT [kWh]:	737.868	737.859
Total [kWh]:	1.204.824	1.204.816
Average COP		
LT [-]:	5,57	1,70
MT [-]:	4,05	2,88
Total [-]:	3,01	2,27
Pumps and fans energy consumption		
LT [kWh]:	772	12.806
MT [kWh]:	32.683	17.300
Total [kWh]:	33.455	30.106
Compressor energy consumption		
LT [kWh]:	83.098	261.349
MT [kWh]:	283.935	238.789
Total [kWh]:	367.033	500.138
Total energy consumption		
LT [kWh]:	83.870	274.155
MT [kWh]:	316.618	256.089
Total [kWh]:	400.488	530.244
Savings		
Yearly energy savings [kWh]:	-	-129.756
Yearly energy savings [%]:	-	-32,4%

The main conclusion of this simulation is that:

“Two one stage systems with constant condensation temperature control will use about 32% more energy than a two-stage transcritical system given the defined load profile and temperature profiles”.

Looking at the results, it might seem strange that COP for LT and MT is higher than the total COP for System 1. Besides the fact that it is difficult to define a COP for a two-stage system (cooling is at two temperatures), the COPs in the summary table are defined as follows for refrigeration:

$$COP_{C,LT} = \frac{Q_{e,LT}}{W_{tot,LT}}$$

$$COP_{C,MT} = \frac{Q_{e,tot,MT}}{W_{tot,MT}}$$

$$COP_{C,total} = \frac{Q_{e,tot,LT} + Q_{e,tot,MT} - Q_{c,LT}}{W_{tot,LT} + W_{tot,MT}}$$

This means for  $COP_{C,MT}$  the useful cooling includes condenser heat of the LT system, while this is not included in the total  $COP_C$ .

For heat pumps, COP is calculated based on delivered heat:

$$COP_{H,LT} = \frac{Q_{c,LT}}{W_{tot,LT}}$$
$$COP_{H,MT} = \frac{Q_{c,tot,MT}}{W_{tot,MT}}$$
$$COP_{H,total} = \frac{Q_{c,tot,LT} + Q_{c,tot,MT} - Q_{c,LT}}{W_{tot,LT} + W_{tot,MT}}$$

## 5 Systems

Pack Calculation Pro contains models of 17 refrigeration system configurations and 2 heat pumps.

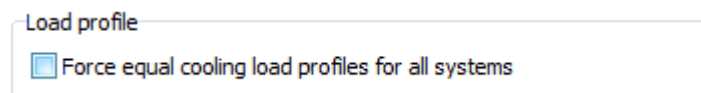
The refrigeration systems can all be equipped with dry expansion evaporators or flooded evaporators, and one stage refrigeration systems can be combined with ground water cooling.

All systems have the possibility to add one or more internal heat exchangers.

Two stage refrigeration systems are specified so that there is load at the medium temperature. So even though it is possible to specify zero load at the medium temperature – making the system resemble a two-stage system with only load at the low temperature – you still specify the medium temperature, for example as -10 °C.

Two stage heat pumps however can be configured with either a floating or fixed intermediate pressure, as neither an extra heat source nor extra load is supported at intermediate pressure at this point.

Pack Calculation Pro allows comparing one stage systems with two stage systems, but you will have to allow the systems to have different load profiles by unchecking the following setting in “Options | Preferences | Calculation | Suction side”:



This will enable you to manually set the same low-temperature load on the systems.

Besides an internal heat exchanger and flooded evaporator, most systems can be extended with a secondary circuit (see chapter 7.1.4).

The buttons on top of the “Setup systems” page will allow you to:

- Add System – adds a new system to your project
- Copy system – makes a copy of the current selected system, incl. compressors and all settings
- Delete system – deletes the current selected system
- Rename system – rename the system to something more descriptive than “System 1”

## 5.1 Groundwater cooling

For one stage systems, you can specify that the mechanical cooling system shall be combined with groundwater cooling.

If you for example define a one-stage system with the following pack configuration:

System 1 (reference)

System configuration | Suction side | Discharge side | **Groundwater cooling**

Reference system

One stage | Two one stage | Cascade | Two stage | Heating

One stage

One stage transcritical

One stage transcritical with ejector

One stage transcritical, parallel compression

One stage transcritical, ejector, parallel compression

Options

Flooded evaporators

System 1

Dimensioning capacity: 171,1 kW

Refrigerant: R-404A

Select compressors from database...

Auto-generated compressor settings...

Compressors:

Bitzer 6F-40.2Y

Pack capacity  $Q_e/Q_c$ : 171,1 kW / 210,6 kW

At Custom, MBP ( $T_e/T_c = 10,0 / 40,0$  °C)

And go to the groundwater cooling page, you will see the following screen:

System 1 (reference)

System configuration | Suction side | Discharge side | **Groundwater cooling**

Groundwater cooling

Cooling:

Dimensioning cooling capacity [kW]: 171.1

Temperature of water into hot well [°C]: 16

Thermal balancing:

Temperature rise of groundwater [K]: 1

Capacity/Power rate for balance cooler [-]: 20

Storage efficiency of groundwater layer: 0.8

Common:

Total pressure drop in piping [bar]: 2

Pump efficiency [-]: 0.5

Custom groundwater temperature:

Groundwater temperature [°C]: 9

Monthly schedule (select months where groundwater cooling is enabled):

January  February  March

April  May  June

July  August  September

October  November  December

A "Storage efficiency" of 1 means that all heat added to the hot well during Cooling has to be removed during Balancing.

A "Storage efficiency" of 0.5 means that only half the heat added to the hot well during Cooling has to be removed during Balancing.

**Cooling**

$\dot{W}_{pump}$ ,  $\dot{Q}_e$ ,  $T_{hotwell\ in}$ ,  $T_{groundwater}$

**Balancing**

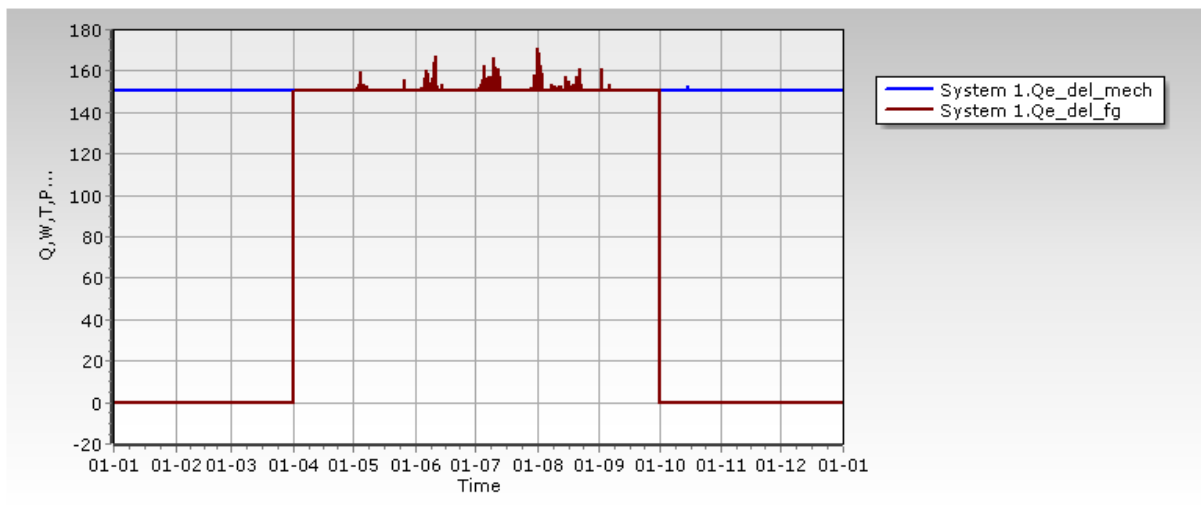
$\dot{Q}_{balancing}$ ,  $\dot{W}_{fan}$ ,  $T_{groundwater}$ ,  $T_{groundwater} + \Delta T$

Note that as default, the dimensioning cooling capacity is automatically set to the same value (taken from the dimensioning cooling capacity of the mechanical refrigeration system).

The simulation of the groundwater cooling system is somewhat simplified:

1. Thermal balancing is always performed. The necessary energy consumption of fans and pumps for doing the thermal balancing is automatically calculated. Whether or not there is time available for doing the balancing is not considered
2. No checks are made whether the cooling does actually make sense... When you specify the evaporation temperature of the suction side, it should be reasonably related to the temperature of the ground water! (it is very difficult for groundwater to perform cooling that requires an evaporation temperature of  $-10\text{ }^{\circ}\text{C}$ ...).

If you for example specify that the groundwater cooling is only available from April to September (assuming balancing is done in the winter months), and the load profile is constant (with an evaporation temperature of  $10\text{ }^{\circ}\text{C}$ ), then you can inspect the delivered cooling on the Calculate|Plots page:



- $Q_{e\_del\_mech}$  is the delivered mechanical cooling which is only active in the winter months
- $Q_{e\_del\_fg}$  is the free cooling + groundwater cooling (which in this case is only groundwater cooling)

The summary page will contain all the details about the groundwater cooling:

	System 1 (reference)
Load fulfillment	
% of time:	100.0
% of energy:	100.0
COP	
Average COP [-]:	7.31
Mechanical [-]:	6.75
Groundwater cooling only [-]:	> 50
Groundwater	
Pump when cooling [kWh]:	5,990
Thermal balancing energy [kWh]:	530,332
Pump and fan for balancing [kWh]:	77,266
Groundwater usage	
Cooling [m <sup>3</sup> /year]:	69,254
Balancing [m <sup>3</sup> /year]:	456,745
Total [m <sup>3</sup> /year]:	525,999
Energy consumption	
Pumps and fans [kWh]:	99,097
Compressor [kWh]:	81,571
Total [kWh]:	180,669
Savings	
Yearly energy savings [kWh]:	-
Yearly energy savings [%]:	-

Note that when COP is larger than 50, "> 50" is just shown.

## 6 Compressor definition in details

You have the option of defining the compressor pack by either selecting between commercially available compressors from the accompanying database, or using auto-generated compressors:

System 1, MT  
Dimensioning capacity  kW  
Refrigerant:  ▼  
  
  
Compressors:  
  
Pack capacity  $Q_e/Q_c$ : 0,0 kW / 0,0 kW  
At Custom, MBP ( $T_e/T_c = -10,0 / 40,0$  °C)

### 6.1 Auto-generating compressors

To get started quickly with calculation, it's enough to select the dimensioning capacity and refrigerant, after which a generic compressor pack is generated using the current design condition.

System 1, MT  
Dimensioning capacity  kW  
Refrigerant:  ▼  
  
  
Compressors:  
  
Generic pack capacity  $Q_e/Q_c$ : 50,0 kW / 72,3 kW  
At Custom, MBP ( $T_e/T_c = -10,0 / 40,0$  °C)

This generic pack is hidden, and it will automatically be updated whenever you change dimensioning capacity, refrigerant, or system type.



### 6.1.1 Auto-generated compressor settings

For more control over how the pack is generated, such as the number of compressors and whether a speed-controlled compressor should be included, click [Auto-generated compressor settings]:

For most refrigerants, auto-generating compressors is only possible with 'Generic' compressor model, which has a fixed isentropic and volumetric efficiency at any condition.

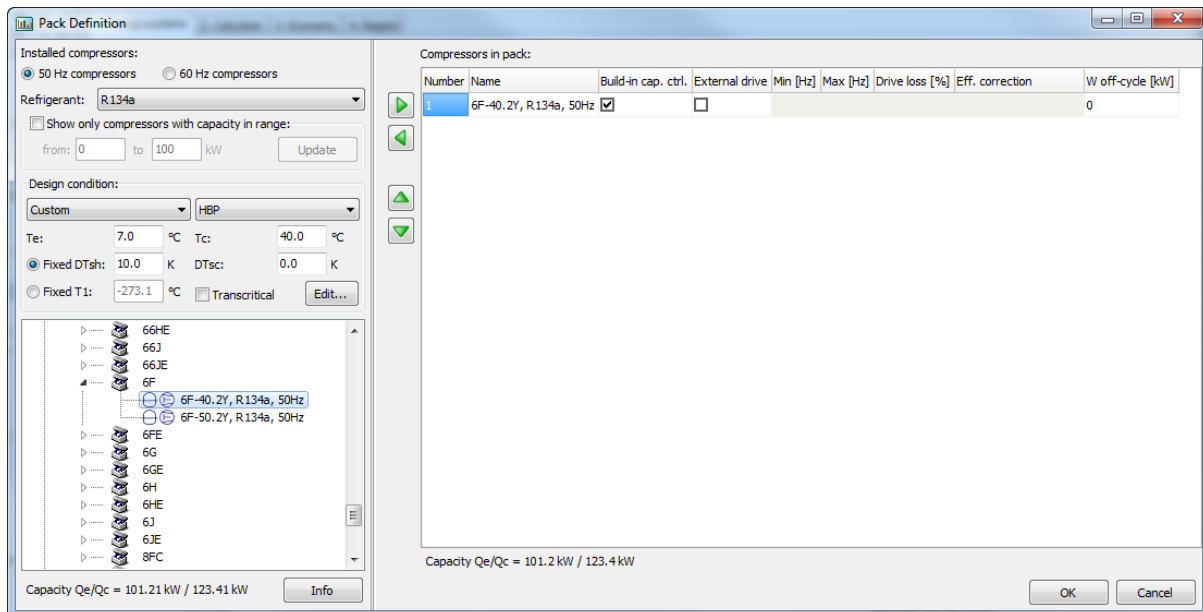
Pack Calculation Pro contains more detailed models of "typical" reciprocating (piston), scroll or screw compressors (including speed control), but only for the following refrigerants: R22, R134a, R410A, R717, and R1270.

When pressing OK, the given inputs are used to generate new compressors, which are now shown, so it's possible to see if there for instance is speed control:

Custom auto-generated compressors are temporarily added to the compressor database, and they are saved together with your project.

## 6.2 Selecting from compressor database

A large selection of compressors is included. When you define compressors for a pack, you have several options to select between as shown below:



To the left, you select frequency and refrigerant to limit the number of compressors you can select between. You can also limit the capacity range of the compressors you want to see – the capacity is calculated from the design condition.

### 6.2.1 Dimensioning - design condition

You should select a design condition which is as close as possible to your expected dimensioning conditions. If you for example design a system for use in a supermarket in Dubai at medium temperature, and you select the design condition to  $T_e = -10\text{ °C}$  and  $T_c = 25\text{ °C}$  and you want 100 kW of cooling, you would probably end up with a too small system as the condensation temperature much of the year will be above  $25\text{ °C}$ , and then the capacity of the compressors will be lower than 100 kW.

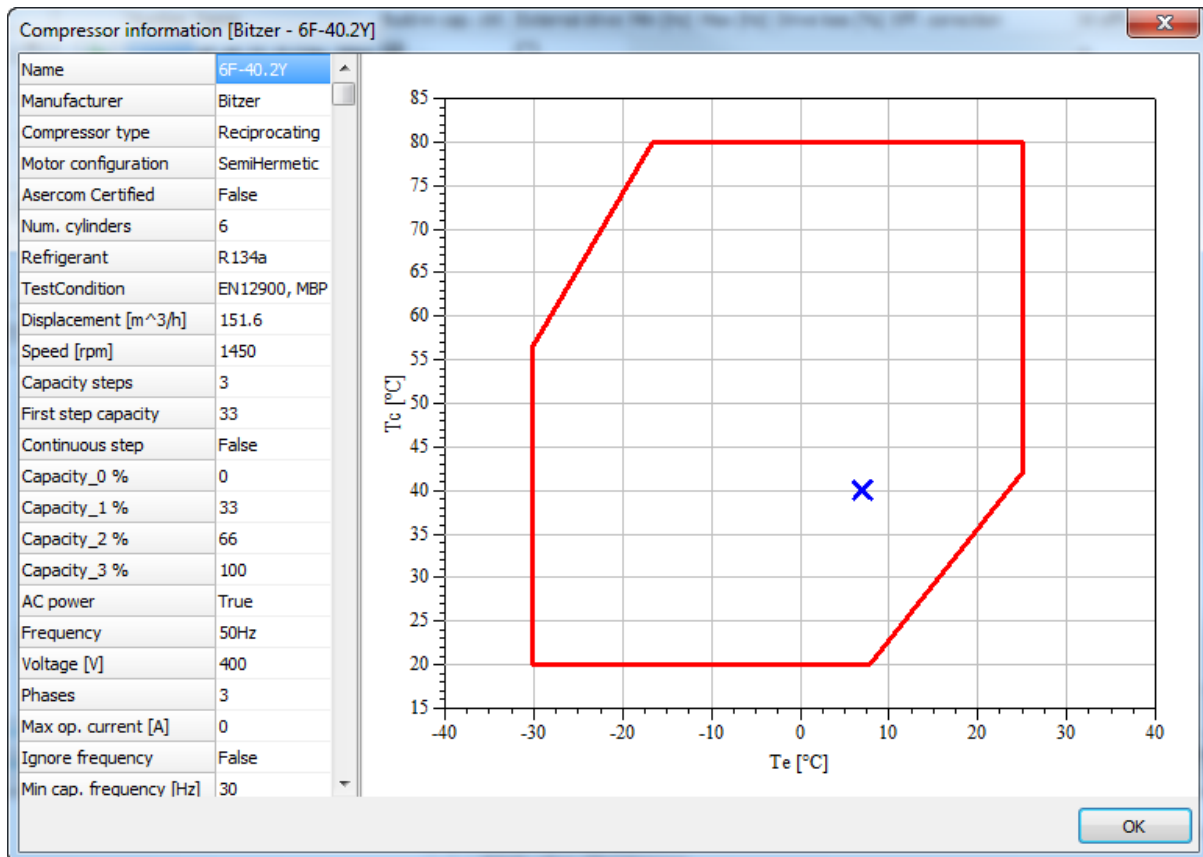
Also the dimensioning capacity of the selected compressor pack (which is a direct consequence of the selected design condition) is used to auto-generate/suggest the size of condenser and evaporator (see chapter 7.1.1 and 8.2.1), so getting the design condition right, will help producing good estimates without much tuning.

For transcritical design conditions,  $P_{gc}$  should be entered instead of  $T_c$ , as in transcritical conditions it's not possible to define a condensing temperature. Similarly, no subcooling occurs transcritically, so the gas cooler outlet temperature  $T_{gco}$  should be entered instead of  $DT_{sc}$ . Other than that, the same guidelines as above should be used.

### 6.2.2 Selecting a compressor

In the compressor tree, you can browse the available compressors and add them to your pack either by double-clicking on the compressor, or by clicking the green right-arrow button.

When you press the Info button, you can see details about the compressor you've selected:



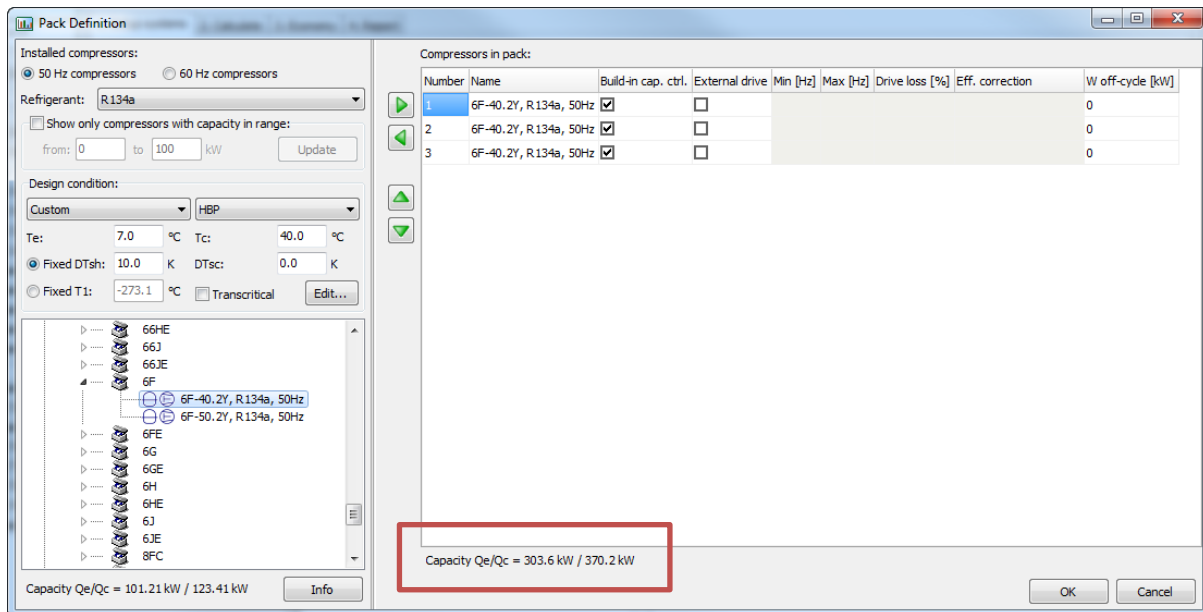
This can be used to check where your design condition is within the operating envelope for the compressor. Note: The same envelope will be used during simulation, to ensure actual evaporation and condensing temperatures throughout the year can be reached by the relevant compressors.

When you have added a compressor to the pack, you have several options for defining the capacity control:

- **Built-in cap. ctrl.** If selected, the built-in capacity control of the compressor is used. Examples of built-in capacity controls are cylinder unloading, slide control, and speed control (if the compressor is sold together with a variable speed drive). If this option is grayed, there is no built-in capacity control (which is the case for most scroll compressors for example).
- **External drive.** If you select this option, you add a variable speed drive to the compressor. If this option is not available, it means that the built-in capacity control of the compressor is a variable speed drive (and you cannot add an external drive on top of a built-in drive). If you select external drive, the following options become available:
  - **Min [Hz]:** The minimum frequency the variable speed drive will run the compressor at.
  - **Max [Hz]:** The maximum frequency the variable speed drive will run the compressor at.
  - **Drive loss %.** Drive loss in percent of compressor power consumption.
  - **Eff. Correction.** Efficiency correction, can be one of the following:
    - **Default.** The program will automatically vary the isentropic and volumetric efficiency of the compressor according to a correction based on the selected compressor type (scroll, recip, screw,...).

- **Constant efficiency.** Keep the isentropic and volumetric efficiency constant (that is they still vary as a function of pressures, but not of speed)
  - **Reciprocating AC motor.** Correct the isentropic and volumetric efficiency as a function of speed, according to a correlation valid for a reciprocating compressor with an AC motor.
  - **Scroll AC motor.** Correct the isentropic and volumetric efficiency as a function of speed, according to a correlation valid for a scroll compressor with an AC motor.
- **W off-cycle.** Here you can specify any power consumption the compressor might have when it's off (for example power to a crank case heater).

Again, it is a good idea to note the dimensioning capacities of the pack you create:



For a one stage refrigeration system you create, the cooling capacity  $Q_e$  will be used as follows:

- The 303.6 kW cooling capacity will be used to:
  1. Auto-dimension the evaporator of a refrigeration system if you select “Known evaporator size” (see 7.1.5):

Evaporation temperature:

Known evaporation temperature:

Profile: Constant

Temperature for constant profile: -10.0 °C

Known evaporator size:

Supply temperature: 12.0 °C

Use non-standard evaporator: ⤴

---

DT: 5.0 K       $Q_e$ : 303.6 kW

2. Scale the cooling capacity profile of a refrigeration system (if you are adding compressors to the reference system):

Cooling capacity:

Profile: Constant

Dimensioning capacity: 303.6 kW ...

Tamb at dimensioning capacity: 32.0 °C

Profile change with ambient temp.: 1.00 %/K

Profile doesn't change if ambient temperature gets below: 20.0 °C

Help

3. Auto-dimension the evaporator of a heat pump:

Use non-standard evaporator: ⤴

<p>At 0 % capacity:</p> <p style="margin-left: 20px;">DT: <span style="border: 1px solid #ccc; padding: 2px;">10.0</span> K</p> <p style="margin-left: 20px;"><math>Q_e</math>: <span style="border: 1px solid #ccc; padding: 2px;">0.0</span> kW</p>	<p>At 100 % capacity:</p> <p style="margin-left: 20px;">DT: <span style="border: 1px solid #ccc; padding: 2px;">10.0</span> K</p> <p style="margin-left: 20px;"><span style="border: 2px solid red; padding: 2px;"><math>Q_e</math>: 303.6 kW</span></p> <p style="margin-left: 20px;">W: <span style="border: 1px solid #ccc; padding: 2px;">9.11</span> kW</p>
---	--

- The 370.2 kW condenser capacity is used to:
  1. Auto-dimension the condenser of a refrigeration system:

Use non-standard air cooled condenser: ⤴

At 0 % capacity: DT: <input type="text" value="12.0"/> K Qc: <input type="text" value="14.8"/> kW	At 100 % capacity: DT: <input type="text" value="12.0"/> K <div style="border: 2px solid red; padding: 2px;">Qc: <input type="text" value="370.2"/> kW</div> Wfan: <input type="text" value="11.11"/> kW
---	---

2. Auto-dimension the condenser of a heat pump system:

Use non-standard condenser: ⤴

DT: <input type="text" value="5.0"/> K Subcooling: <input type="text" value="2460.4"/> K	<div style="border: 2px solid red; padding: 2px;">Qc: <input type="text" value="370.2"/> kW</div>
---	---

If you are setting up compressors for a two-stage system or a heat pump, you'll find that the dimensioning capacities are also used to auto-dimension heat exchangers and auto-scale load profiles.

### 6.3 Capacity control

The order in which you add compressors to your pack is important. At a given load in each hour with given ambient conditions, PackCalc will automatically cut-in compressors as needed starting from the first in your pack, following the rules below:

#### 6.3.1 On-off compressors pack

If the pack only contains compressors which are turned on/off - including cylinder unloading - then calculation is done as follows:

- Find minimum number of compressors with total capacity larger than required
- Find maximum number of compressors with total capacity lower than required
- The requirement, the minimum and the maximum is used to calculate and weight the result:

#### Calculation example:

- The load from the load profile is 20 kW
- The compressor pack has two stages, and the evaporation temperature is -10 °C

Capacity stages:

	Cooling capacity [kW]	Evaporation temperature [°C]	Condensation temperature [°C]
Stage 0	0	-	-
Stage 1	15	-10	35
Stage 2	30	-10	40

To get 20 kW cooling capacity within an hour on average, the system needs to operate 66% of the time (40 min) in Stage 1, and 33% of the time (20 min) in Stage 2.

Note that the condensation temperature will change between the two stages. The condenser stays the same, so in stage 1 the low heat load at the same ambient can be rejected at a lower condensation temperature.

So besides doing 8760 calculations, each capacity of the pack is actually checked every hour (in a slightly more clever way however).

### 6.3.2 Continuous controlled compressor

When a speed controlled compressor – or more generally a continuous capacity controlled compressor as for example a glide controlled screw compressor – is included in the pack, the capacity control is in principle exactly the same as for on/off compressors, except that the continuous controlled compressor always has priority, meaning:

- First PackCalc tries to satisfy the required cooling using the continuous controlled compressor
- If this doesn't succeed, then the next compressor is cut in, and then the capacity of the continuous controlled compressor is varied again

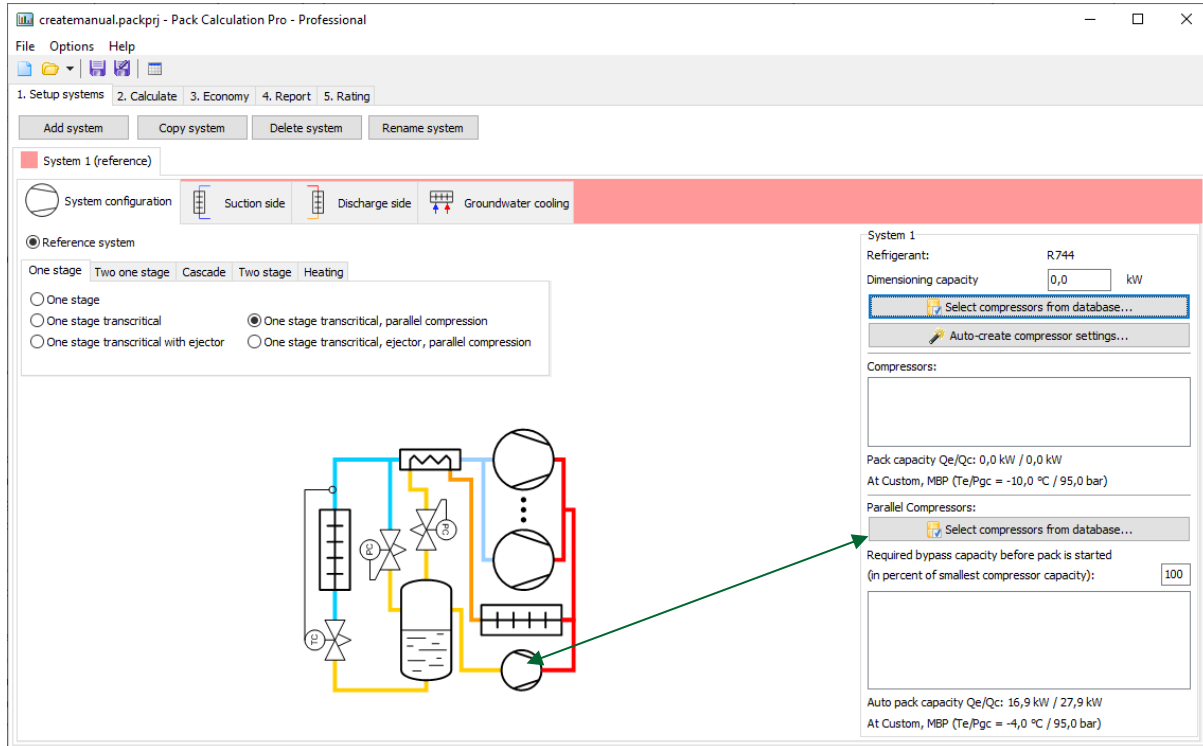
If the above procedure doesn't succeed, then it's because:

- Required cooling is lower than the minimum capacity of the continuous controlled compressor. In this case the continuous controlled compressor is run on/off at the minimum capacity
- Required cooling cannot be matched using a number of fixed speed compressors and the continuous controlled compressor. In this case the continuous controlled compressor is run on/off at the minimum capacity together with the fixed speed.
- Required cooling is higher than the maximum capacity of the pack – in this case a warning is issued.

Note that even though you can add more than one continuous controlled compressor to a pack, PackCalc will only vary the capacity of the first continuous controlled compressor in the pack. The rest will just run on/off at maximum capacity.

## 6.4 Parallel Compression

You can select transcritical one- and two-stage systems where the gas bypass (in defined periods) is done through one or more parallel compressors, instead of the bypass valve. Using parallel compressors in transcritical systems will contribute to energy savings – especially in hot climates.



Adding parallel compressors works just like adding normal compressors. The only extra parameter is the “Required bypass capacity...” value – let’s call it  $X$  in the following.

For every hour, the mass flow in the bypass,  $\dot{m}_{bp}$ , is calculated. If the *lowest capacity step of the smallest parallel compressor* is larger than  $X \cdot \dot{m}_{bp}$ , the bypass flow is handled by the parallel compressors, else everything is handled by the bypass valve.

The lower  $X$  value you specify, the more running time the parallel compressors will get, but there’s also a chance of very frequent start/stops if bypass flow is small.

If the parallel pack is not large enough to support all flash gas, the parallel pack is controlled to run at full capacity, and the bypass valve is opened to maintain the same suction pressure.

Note: Pack Calculation Pro does not contain valve data, therefore it’s not possible to control specific valve opening degrees.



## 7 Suction side in details

The suction side definition will look different depending on whether you are defining a refrigeration system or a heat pump.

### 7.1 Refrigeration system

In a refrigeration system the suction side area can contain the following elements:

- Cooling capacity
- Dry expansion evaporators
- Flooded evaporators
- Secondary circuit
- Evaporation temperature
- Additional

For example, for a two-stage system, you'll have to specify both the MT and LT suction sides.

#### 7.1.1 Cooling capacity

When defining the Cooling capacity, you have the following options:

- **Profile.** You can select from a set of predefined profiles from the drop down list, or you can define your own profile by pressing the [Profile] button (see below).
- **Dimensioning capacity.** This value defines the size of the selected profile (profiles are relative). The dimensioning capacity of the selected compressor pack is entered as the default value by the program
- **Tamb at... etc.** The last three parameters define how the selected profile varies with ambient temperature. You can press the [Help] button to see an explanation of how the parameters influence the cooling capacity. If you want a truly constant profile, with no variation with ambient temperature, you should set **Profile change with ambient temp.** to 0 %/K and **Profile doesn't change if...** to a very low value (for example -100 °C).

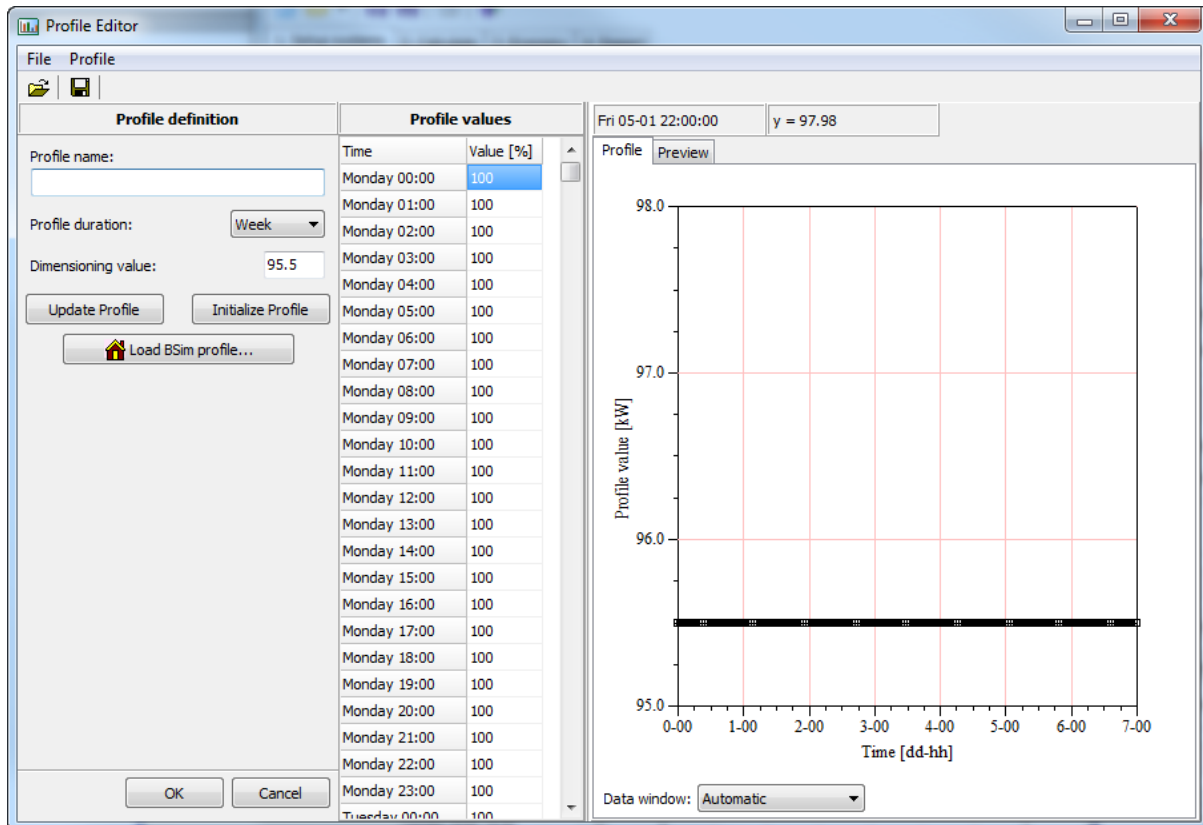
You can (normally) only change the cooling capacity section for the reference system – i.e., the program enforces use of the same load profile for all systems you compare. Also note that when comparing one-stage with two-stage systems, the one-stage cooling capacity is handled by the

LT suction side in any two-stage systems. If you want to compare systems with different load profiles, you should deselect the following option in Options | Preferences | Calculation | Suction side:

Load profile

Force equal cooling load profiles for all systems

When you press the [Profile] button, you'll see the following dialog:



Here you specify the load profile for the system.

The default (included with the program) profiles have duration of typically one week.

Whenever you make changes to the profile, you should press [Update Profile].

When you press the “Load BSim profile” button, you can load results from BSim simulations directly into the program. The file you load should have duration of one year and contain values for each hour – see Appendix A.

It is also possible to import/export from/to Excel (.csv, comma-separated file).

Remember to save your profile, either with the same or a new name, before closing the dialog. If you do not save changes, the previous version of your profile will be reloaded.

### 7.1.2 Dry expansion evaporators

Dry expansion evaporators:	
Total superheat:	20.0 K
Non-useful superheat:	10.0 K

For dry expansion evaporators you specify the total superheat and the non-useful superheat.

The non-useful superheat is the superheat in the suction line, which together with the superheat in the evaporator, gives the total superheat. The suction temperature at the compressor pack equals the evaporation temperature plus the total superheat.

### 7.1.3 Flooded evaporators

If you have selected flooded evaporators when setting up the system, this option will appear.

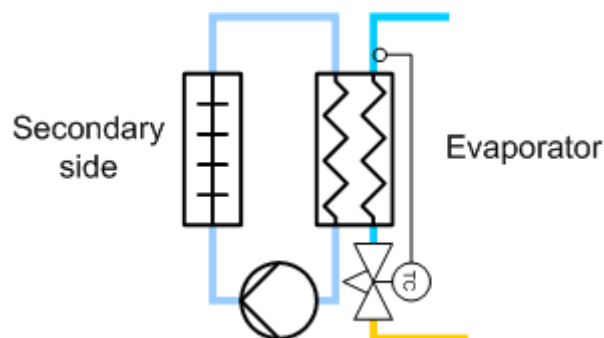
Flooded evaporators:	
<input checked="" type="checkbox"/> Forced circulation:	
Nominal pump power:	0.100 kW
<input checked="" type="radio"/> Power proportional to capacity <input type="radio"/> Constant power	

For flooded evaporators, the suction temperature at the compressor pack is assumed equal to the evaporation temperature. If the refrigerant circulation to the evaporators is forced – i.e. refrigerant pump(s) are used – you can specify the power consumption of the pump(s).

### 7.1.4 Secondary circuit

<input checked="" type="checkbox"/> Secondary circuit:	
Secondary pump power:	1.000 kW
<input checked="" type="radio"/> Power proportional to capacity <input type="radio"/> Constant power	

You also have the possibility to add a secondary circuit feeding the cooling places:



And if you select a secondary circuit, you will include pump power in the total energy consumption.

Note that secondary circuits are not enabled when “Known evaporator size” is selected (it's only available for “Known evaporation temperature”). See also chapter 7.1.5.

### 7.1.5 Evaporation temperature

For a one stage system – as the only one – you have the option of selecting between “Known evaporation temperature” and “Known evaporator size”. For any other system, you can only select “Known evaporation temperature”.

The difference between the two is that:

- For “Known evaporation temperature”, you specify the evaporation temperature – either as a constant or following a profile
- For “Known evaporator size” you specify the supply temperature and the “size” (UA-value) of the evaporator and the program then calculates the evaporation temperature

**Known evaporation temperature** For “Known evaporator size”, the evaporation temperature will vary according to the load on the evaporator and the compressor capacity, which again means that if you want to show energy savings using for example a speed controlled compressor, then you should as far as possible try to select “Known evaporator size” – this will automatically make Pack Calculation Pro include savings due to the fact that you are able to raise the evaporation temperature during low load situations.

You must give a profile for the evaporation temperature – either a constant profile (= constant value), one of the installed profiles, or by defining the profile yourself by pressing the [Profile] button.

**Known evaporation temperature** If you select “Known evaporation temperature” then the evaporation temperature is given, and you will have to manually raise the evaporation temperature to show savings using a variable speed compressor (see also appendix E).

You should define the supply temperature – which currently can only be a constant value. Also, you have the possibility to define the dimensioning capacity and temperature difference of the evaporator, or just accept the default values, which are based on the capacity of the selected

compressor pack and a default temperature difference (which can be changed in Preferences – see chapter 0).

### 7.1.6 “Additional” section

The additional section will contain a selection of additional input options, depending on the selected system.

For all systems, “Internal heat exchanger efficiency” is an option. The efficiency can be between 0 (no heat exchanger) and 1 (ideal heat exchanger). Normally a value of 0.2 to 0.6 is reasonable (see also appendix A).

Other additional input options are explained below:

System	Values	Meaning
<b>Cascade</b>	Cascade temperature difference	Temperature difference between condensation temperature of LT system and evaporation temperature of MT system
<b>Cascade transcritical</b>	Cascade temperature difference	See above
<b>Cascade CO2</b>	CO2 pump power	Power usage of CO2 pump
	Cascade temperature difference	See above
<b>Two stage closed intercooler</b>	Intercooler heat exchanger efficiency	Thermal efficiency of intercooler, see also appendix A
<b>Ejector</b>	Minimum ejector pressure lift	Limit below which gas bypass valve is opened, and ejector is disabled. See also Appendix C.1.3

## 7.2 Heat pumps

For heat pumps, the suction side contains the following elements:

- Evaporator capacity control
- Additional
- Non-standard evaporator

### 7.2.1 Evaporator type

Under Evaporator type, you specify the heat source for the heat pump (either ground or air):

Evaporator type:	
<input checked="" type="radio"/>	Ground source
<input type="radio"/>	Air source

### 7.2.2 Evaporator capacity control

Evaporator capacity control:	
<input checked="" type="radio"/> Constant Te:	<input type="text" value="0.0"/> °C
<input type="radio"/> Te = Tamb -	<input type="text" value="9.0"/> K
<input type="radio"/> Fan/pump running with compressor(s)	
Maximum Te:	<input type="text" value="15.0"/> °C
Total superheat:	<input type="text" value="10.0"/> K
Non-useful superheat:	<input type="text" value="0.0"/> K
<input type="checkbox"/> Speed controlled fans/pump	

When specifying the evaporator capacity control method, you have 3 choices:

1. **Constant Te**, which means that the system will control evaporator fans (and pumps if any) so that the evaporation temperature is kept constant at the specified value. If the system cannot maintain the defined value (for example if the source temperature is below the wanted value) then the system will automatically lower the temperature until the capacity can be fulfilled.
2. **Te = Tamb-**. In this scenario, the system will try to keep a certain difference between the evaporation temperature and the source temperature
3. **Fan running with compressor(s)** where the fans and/or pumps are running full speed whenever the compressors are running, and Te is varied depending on evaporator load.

Furthermore, you can specify:

- **Maximum Te**, which is the maximum allowable evaporation temperature
- **Total superheat**, which is the sum of useful superheat (superheat inside evaporator) and **non-useful superheat** (superheat outside evaporator – typically in the suction line)

- **Speed controlled fans/pump** which apply speed control to fans/pumps (see also appendix B).

Pack Calculation Pro does not distinguish between pumps and fans – they are modelled the same way (see also appendix B).

### 7.2.2.1 Two-stage heat pump control

For two-stage heat pumps, evaporation pressure control of the top stage is controlled differently:

Evaporator capacity control:	
<input checked="" type="radio"/> Constant Te:	<input type="text" value="0,0"/> °C
<input type="radio"/> Equal pressure ratios	
Maximum Te:	<input type="text" value="15,0"/> °C

This provides the following new option:

- **Equal pressure ratios**, in which case intermediate pressure of the two-stage system is controlled so pressure ratios in the two stages are approximately equal.

### 7.2.3 Additional

Additional	
Internal heat exchanger efficiency:	<input type="text" value="0,40"/> [0-1]

In additional you specify the and the efficiency of an internal heat exchanger (if none, then set efficiency to 0 – see appendix A)

### 7.2.4 Non-standard evaporator

The available inputs depend on the type of evaporator selected: For an air-source evaporator, it's possible to define evaporator capacity with fans/pumps turned off, which is not possible for ground-source evaporators:

<input type="checkbox"/> Use non-standard air source evaporator: ⤴			
At 0 % capacity:		At 100 % capacity:	
DT:	<input type="text" value="15,0"/> K	DT:	<input type="text" value="15,0"/> K
Qe:	<input type="text" value="0,7"/> kW	Qe:	<input type="text" value="17,8"/> kW
		Wfan:	<input type="text" value="0,53"/> kW

<input type="checkbox"/> Use non-standard ground source evaporator: <span>⤴</span>				
At design (100% capacity):				
DT:	<input type="text" value="10,0"/>	K	Wpump: <input type="text" value="0,53"/>	kW
Qe:	<input type="text" value="17,8"/>	kW		

By default, the evaporator is automatically selected using the cooling capacity of the selected compressors at the design condition, and default values from Options|Preferences.

The capacity and temperature differences are used to calculate a UA-value of the evaporator, which is then used to calculate the power consumption of fans/pumps depending on the needed capacity in a given situation. The calculations are described in detail in appendix B.

### 7.2.5 Non-standard cascade heat exchanger

<input type="checkbox"/> Use non-standard cascade heat exchanger: <span>⤴</span>					
DT:	<input type="text" value="5,0"/>	K	Qe:	<input type="text" value="37,3"/>	kW

By default, the cascade heat exchanger is automatically dimensioned for the cooling capacity of the selected MT compressors at design condition, and default values from Options|Preferences.

The capacity and temperature differences are used to calculate a UA-value of the evaporator, which is used to find the condensing / evaporation temperature. The calculations are described in detail in appendix B.



## 8 Discharge side in details

Specifying the discharge side is different whether you are defining a refrigeration system or a heat pump.

### 8.1 Refrigeration system

For a refrigeration system, specifying the discharge side is about defining:

- Condenser type – the different types are treated in detail in appendix B, here only air-cooled condenser will be shown.
- Condenser capacity control method
- Size of the condenser
- If desired, adding free cooling and/or heat recovery

The condenser capacity control parameters are slightly different between transcritical and subcritical systems, but common for both is that if the wanted condensation temperature (i.e., the temperature found by the specified control algorithm) cannot be obtained, the condensation temperature is automatically raised until the required capacity is reached.

This could for example occur if the control algorithm dictates that the condensation temperature should be constant at 30 °C and the ambient temperature is 35 °C... Then PackCalc will automatically find the condensation temperature (keeping all fans/pumps running 100%) where the condenser is able to reject the required heat. Note though that the required heat rejection changes as the condensation temperature changes, so this will require iteration – and if no solution is found, a warning is issued.

Calculating the power consumption of condenser fans and pumps is explained in detail in B, but in general it works like this:

- If fans (or pumps) are fixed speed, then it is assumed that there are an infinite number of fans and that the condenser capacity and power consumption vary linearly with the number of fans that are cut in.
- If fans (or pumps) are variable speed, then it is assumed that there the condenser capacity and power consumption vary according to a power law with the speed of the fans.

Note that this procedure will slightly underestimate the power consumption associated with fixed speed fans. Normally there is a limited number of fixed speed fans, and when cutting fans in and out, it will have the effect of increasing/decreasing the condensation temperature (the exact capacity needed is rarely matched using fixed speed fans). This variation in condensation temperature increases the energy consumption of the system and this increase is not simulated in PackCalc.

### 8.1.1 Transcritical condenser control parameters

A transcritical system will also have to operate subcritically, so there are inputs for both subcritical and transcritical control:

Subcritical control:	
Tc = Tamb +	7.0 K
Minimum Tc:	10.0 °C
Subcooling:	2.0 K
<input type="checkbox"/> Speed controlled fans	

Controller parameters:	
Min transcritical temp:	29.0 °C
Max subcritical temp:	26.0 °C
TC Factor 1:	2.6 -
TC Factor 2:	0.0 -

When the gas cooler/condenser for a transcritical system is running subcritical, the program accepts the following settings:

- **Tc = Tamb+b.** You specify the control algorithm for the condensation temperature by specifying “b”. Default is to control the capacity of the condenser fans so that the condensation temperature is 7 K above the ambient temperature.
- **Minimum Tc.** Minimum allowable condensation temperature. Default is 10 °C for transcritical systems (even at 10 °C there is normally plenty of pressure difference across the expansion valve)
- **Subcooling.**
- **Speed control.** You can select whether fans (and/or pumps if any) are speed controlled.

When the system is running transcritical, it is assumed that all fans (and pumps) are running 100% and that therefore the condenser (now acting as a gas-cooler) is able to maintain a temperature to the ambient at the gas cooler outlet of 2 K at the dimensioning load. The 2 K temperature difference is decreased linearly with the load starting at 2 K at dimensioning load and decreasing to 0 K at no load. The 2 K can be changed in the Options|Preferences menu:

Gas cooler controller parameters:			
Minimum transcritical temperature:	29.0 °C	TC Factor 1:	2.6 -
Maximum subcritical temperature:	26.0 °C	TC Factor 2:	0.0 -
Default DT gas cooler out at dimensioning load when running transcritical:			2.0 K
<input type="button" value="Default values"/>			

Furthermore, you can specify the following controller parameters, which corresponds to high pressure control settings as explained below:

- **Min transcritical temp.** Above this temperature, the controller operates in transcritical mode
- **Max subcritical temp.** Above this temperature and below the **Min transcritical temp** the controller operates in transition mode. Below this temperature, the controller operates in subcritical mode.

- **TC Factor 1, 2.** Decide how high pressure is controlled in transcritical mode, according to the following equation:

$$P_{gascooler}[bar] = P_{crit} - (dT_{transcritical} \cdot TC_{factor,2} - TC_{factor,1}) \cdot dT_{transcritical}$$

$$dT_{transcritical}[K] = T_{gascooler,out} - T_{transcritical,min}$$

- In transition mode, a polynomial is used which sets pressure based on minimum transcritical temperature and maximum subcritical temperature, and to subcooling.

### 8.1.2 Subcritical condenser control parameters

Condenser capacity control:	
<input checked="" type="radio"/> Constant Tc:	30.0 °C
<input type="radio"/> Tc = Tamb +	9.0 K
<input type="radio"/> Fan running with compressor(s)	
Minimum Tc:	20.0 °C
Subcooling:	2.0 K
<input type="checkbox"/> Speed controlled fans	

If the system is not transcritical, you can select two other condenser capacity control methods (besides **Tc = Tamb+b**):

- **Constant Tc.** The program tries to keep the selected condensation temperature throughout the year.
- **Fan running with compressor(s).** If selected the fans (and pumps, if any) will run 100% all the time – but only when one or more compressors are running.

### 8.1.3 Non-standard air-cooled condenser

Use non-standard air cooled condenser: <span>⌵</span>	
At 0 % capacity:	At 100 % capacity:
DT: <input type="text" value="12.0"/> K	DT: <input type="text" value="12.0"/> K
Qc: <input type="text" value="5.6"/> kW	Qc: <input type="text" value="138.9"/> kW
	Wfan: <input type="text" value="4.17"/> kW

As default the condenser is auto-dimensioned, using the condensation capacity of the selected compressors at the design condition, plus default values from Options|Preferences.

For transcritical systems, the condenser is auto-dimensioned using the capacity of the selected compressor pack at a sub-critical condition at 25 °C (can be changed in Options|Preferences). For a subcritical system, the specified design condition of the compressor pack is used to auto-select the needed condenser capacity.

The capacity and temperature differences are used to calculate a UA-value of the condenser, which is then used to calculate the power consumption of fans/pumps depending on the needed capacity in a given situation. The calculations are described in detail in appendix B.

### 8.1.4 Free cooling

Free cooling can be added to a system. The calculations are designed for indirect free cooling, where heat exchangers with fans are added both inside and outside, and water or a brine is pumped between them, when ambient conditions allow.

The supply temperature (on the cold side) for free cooling should be reasonably related to the supply temperature when using mechanical cooling, so at least higher than the evaporation temperature.

In two-stage systems, only the medium temperature (MT) cooling load can be covered by free cooling, so the MT compressors still operate if there also is freezing (LT) load.

You can control when free cooling is activated by setting the control method:

At 0 % capacity:		At 100 % capacity:			
DT:	10.0 K	DT:	10.0 K	Wfan:	2.44 kW
Q:	3.8 kW	Q:	95.5 kW	Wpump:	0.43 kW

If you select On/Off, free cooling is turned on when the ambient temperature is below the specified limit. If you choose Continuous, the program increases the free cooling capacity linearly from 0 to 100% when the ambient temperature is within the specified limit. When free cooling delivers all cooling capacity, the refrigeration system (compressors, fans, pumps) will be turned off.

When specifying free cooling, you also must whether fans and the pump are speed controlled. A standard free cooler is automatically sized from the dimensioning cooling capacity, but it's possible to specify a custom size.

The capacity and temperature differences are used to calculate a UA-value of the evaporator, with which the power consumption of fans/pumps is calculated based on current operating conditions. The calculations are described in detail in appendix B and the default values can be changed in Options|Preferences.

### 8.1.5 Heat recovery

If heat recovery is enabled, you can select between two control strategies:

Heat recovery

Refrigerant temp. out of recovery heat exchanger:  °C

Heat recovery is a function of ambient temperature:

Start heat recovery when T\_amb =  °C

At start keep high pressure at:  °C

Maximum heat recovery when T\_amb =  °C

High pressure at maximum heat recovery:  °C

Run heat recovery at all times:

Keep high pressure at:  °C

Monthly schedule (select months where heat recovery is enabled):

<input checked="" type="checkbox"/> January	<input checked="" type="checkbox"/> February	<input checked="" type="checkbox"/> March	<input type="text" value="Q1"/>
<input checked="" type="checkbox"/> April	<input checked="" type="checkbox"/> May	<input checked="" type="checkbox"/> June	<input type="text" value="Q2"/>
<input checked="" type="checkbox"/> July	<input checked="" type="checkbox"/> August	<input checked="" type="checkbox"/> September	<input type="text" value="Q3"/>
<input checked="" type="checkbox"/> October	<input checked="" type="checkbox"/> November	<input checked="" type="checkbox"/> December	<input type="text" value="Q4"/>

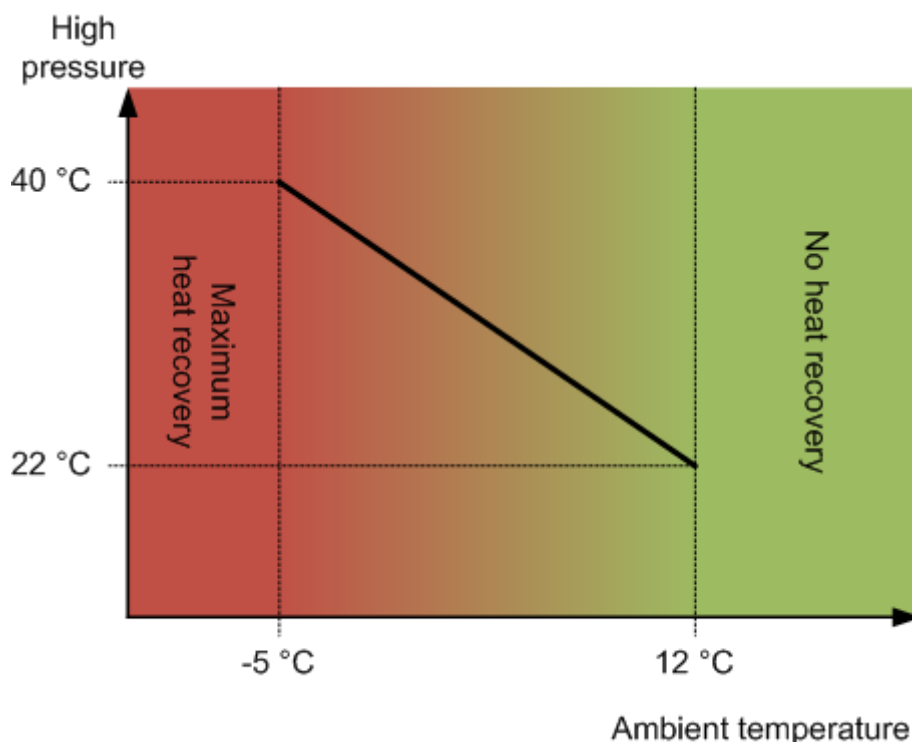
First you specify the wanted refrigerant temperature out of the heat recovery heat exchanger (which essentially defines how much of the heat in the discharge gas you use). Then you select the control method, which can be:

- A function of ambient temperature, where the high pressure (condensation pressure) is varied between the specified start and end temperature according to the specified ambient temperature limits.
- Constant, where the high pressure (as a minimum) is kept at a certain value when heat recovery is active.

Furthermore, you can specify a monthly schedule for the heat recovery function.

In general, you can say that the heat recovery function is overwriting the condenser control method, if the condensation pressure is below the one dictated by the heat recovery.

The heat recovery function is illustrated below (when it is a function of ambient temperature):



## 8.2 Heat pump

Defining the discharge side of a heat pump involves:

- Specifying the heating capacity
- Defining the supply temperature
- Defining the size of the condenser

### 8.2.1 Heating capacity

Heating capacity:

Profile: HeatPump\_test

Dimensioning capacity: 370.2 kW

Day mean Tamb at dimensioning capacity: -12.0 °C

Profile change with mean ambient temp.: 4.00 %/K

No heating if mean ambient temperature gets above: 13.0 °C

Help

The heating capacity – that is the required heating – of the heat pump is specified in almost the same way as for the cooling capacity for refrigeration systems.

The load profile is specified the same way, but the only difference is that the heating profile is varied with the ambient mean temperature (the mean ambient temperature at a given hour equals the mean ambient temperature at that day).

### 8.2.2 Supply temperature

Supply temperature:

Constant temperature: 30.0 °C

Day/night variation

Day temperature: 30.0 °C

Night temperature: 25.0 °C

The supply temperature can be either constant or a function of the time. Day is defined as 07:00 to 22:00.

### 8.2.3 Non-standard condenser

Use non-standard condenser:			
DT:	5.0 K	Qc:	370.2 kW
Subcooling:	2.0 K		

As default the condenser is auto-dimensioned, using the condenser capacity of the selected compressors at the design condition, plus default values from Options|Preferences.

The capacity and temperature differences are used to calculate a UA-value of the condenser, which is then used to calculate the condensation temperature (using the supply temperature give above). The calculations are described in detail in appendix B.

Note that the power consumption of fans/pumps used to distribute the condenser heat is not included in the calculation.



## 9 Results - year calculation

When all systems have been defined, you are ready to calculate the yearly energy consumption, by moving to the "Calculate" page.

When you press the [Calculate] button you will automatically be moved to the "Monthly energy consumption" page to see the results of the simulation.

When the simulation has finished, an icon next to the calculate button will indicate the result:



One or more warnings have been raised. Open the Warnings page to see details about the warning(s).



Calculation finished without problems or warnings

The individual pages on the "Calculate" page are explained now.

## 9.1 Conditions

On the “Calculate|Conditions” page, you have the following options:

1. Setup systems 2. Calculate 3. Economy 4. Report

Calculate 00:00:00

Conditions Monthly energy consumption Summary Plots

Reference year:  
 Copenhagen DRY

Adjust ambient temperature by adding: 0 K

Schedule

Monthly schedule (select months):

<input checked="" type="checkbox"/> January	<input checked="" type="checkbox"/> February	<input checked="" type="checkbox"/> March	Q1
<input checked="" type="checkbox"/> April	<input checked="" type="checkbox"/> May	<input checked="" type="checkbox"/> June	Q2
<input checked="" type="checkbox"/> July	<input checked="" type="checkbox"/> August	<input checked="" type="checkbox"/> September	Q3
<input checked="" type="checkbox"/> October	<input checked="" type="checkbox"/> November	<input checked="" type="checkbox"/> December	Q4

Week schedule

Operating:		From:	To:
<input checked="" type="checkbox"/> Monday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Tuesday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Wednesday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Thursday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Friday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Saturday	<input checked="" type="checkbox"/> All day	08:00	18:00
<input checked="" type="checkbox"/> Sunday	<input checked="" type="checkbox"/> All day	08:00	18:00

Controlled by ambient temperature:  
 Run only when temperature is above: 0 °C

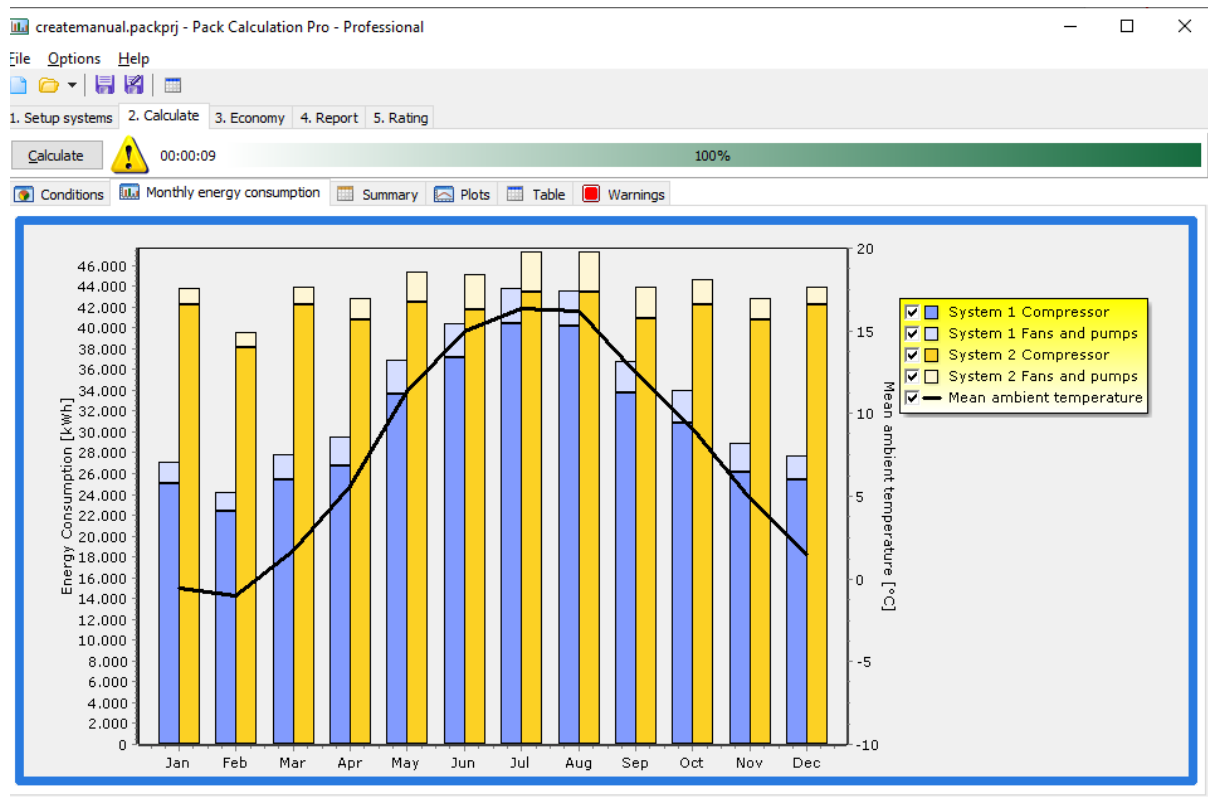
You should first select a reference year. The selection you make will be saved as default when you close Pack Calculation Pro.

If you want, you can add a temperature difference to adjust the selected ambient temperature profile – if you for example enter -1 K then all ambient temperatures will be decreased by 1 K.

If your system is not running all year, you can define periods where the system is stopped. You can also select a control strategy where the system is only running if the ambient temperature is above a certain value.

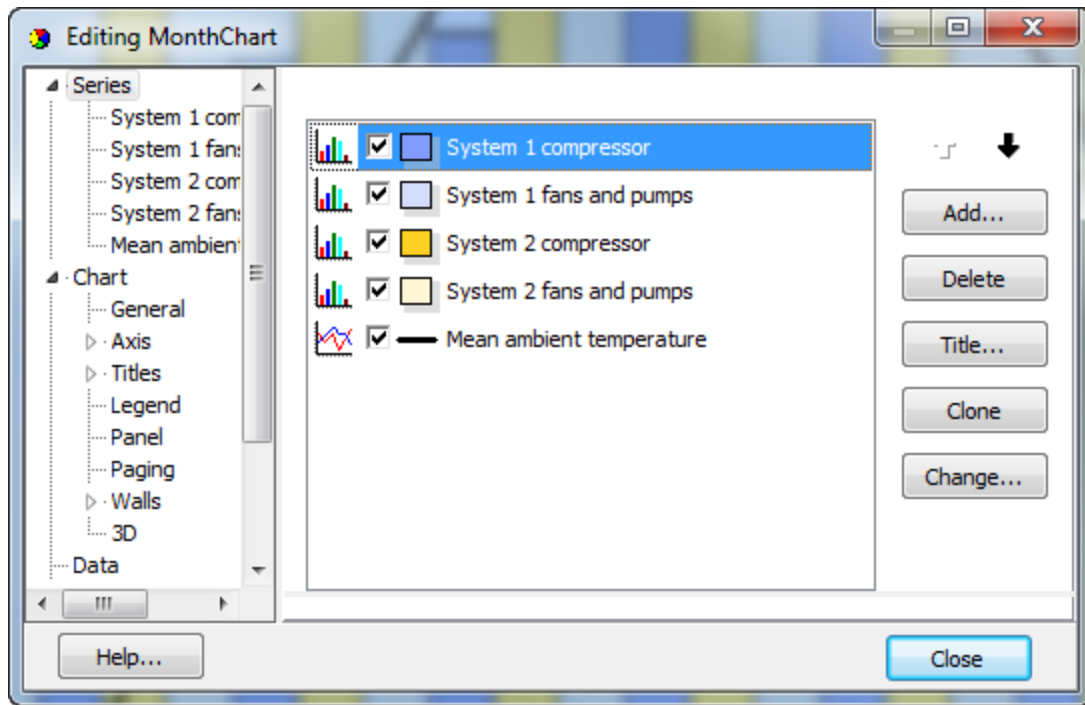
## 9.2 Monthly energy consumption

The monthly energy consumption page shows the result of your calculation on a monthly base. All results are divided into compressor and fan/pump/other:



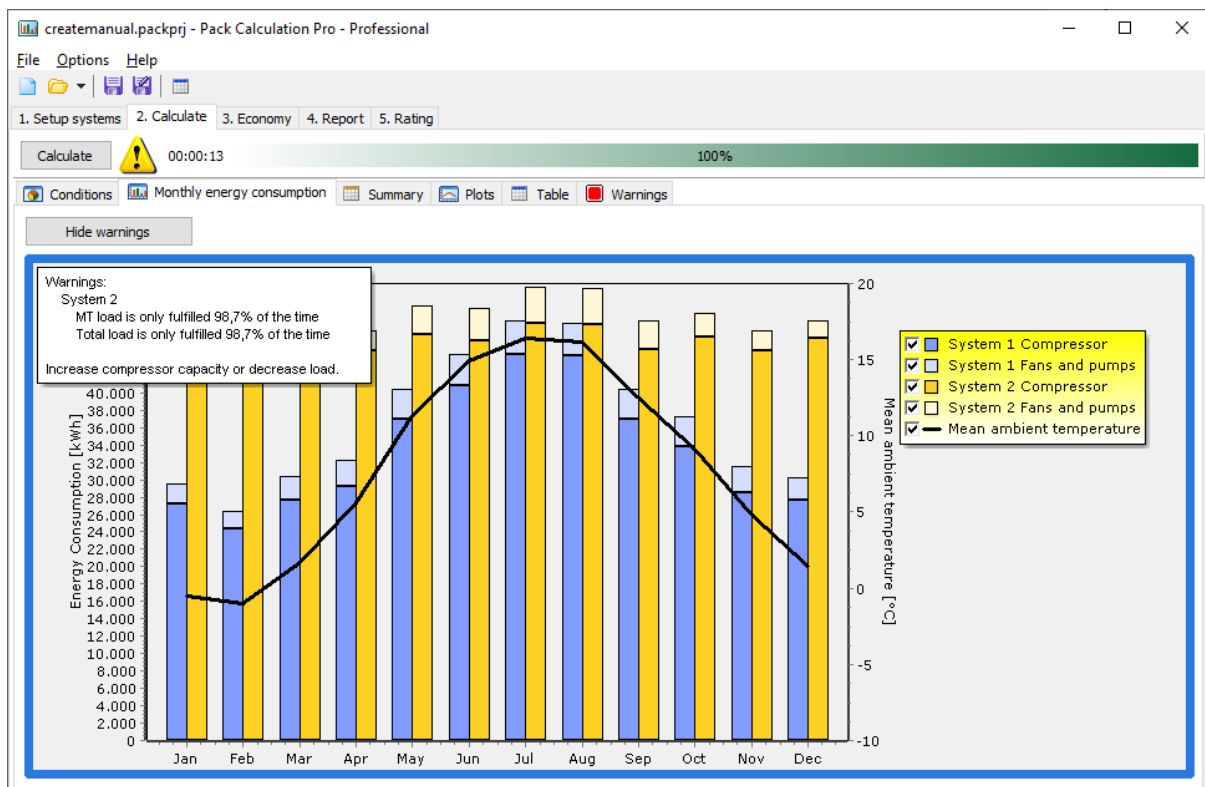
The 'Mean ambient temperature' relates to the driving ambient temperature for the last simulated system in the project, which depending on condenser type can be wet-bulb, dry-bulb or, for water-cooled systems, the water temperature. If you wish to plot the driving ambient temperature per system, this can be done from the "Plots" page, look for the curves named TCondAmb.

If you double-click on the graph, you will see the following dialog where you can format the graph in details:



If for some reason you have included a system which has insufficient capacity – i.e., is not able to fulfil the required cooling or heating capacity, then two things will happen:

1. This system will typically come out as the system with the lowest energy consumption (not surprisingly as it does not deliver the required cooling)
2. A warning will be shown directly on the monthly energy consumption chart:



Note that this warning will only be shown if the load fulfilment (either in respect to time or energy) is less than 99%.

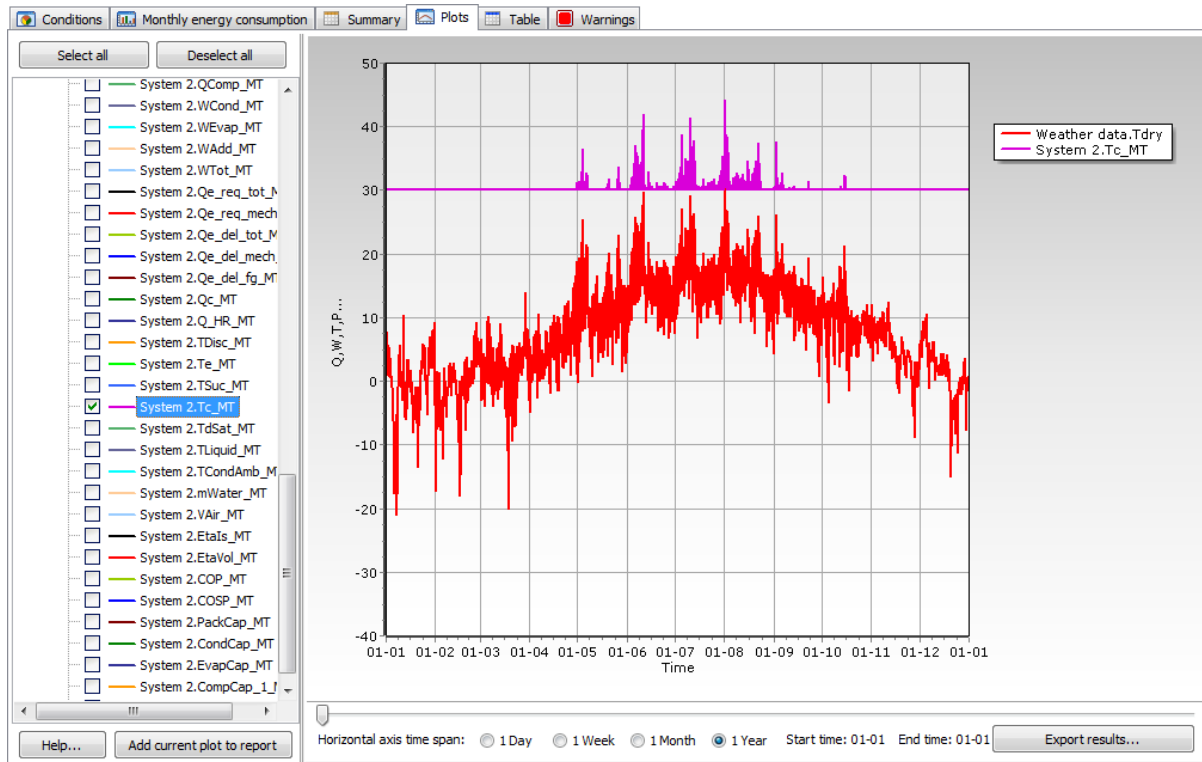
### 9.3 Summary

The summary page compares the energy consumption of the defined systems:

	System 1 (reference)	System 2
Load fulfilment in % of time		
LT:	100,0%	100,0%
MT:	100,0%	100,0%
Total:	100,0%	100,0%
Load fulfilment in % of energy		
LT:	100,0%	100,0%
MT:	100,0%	100,0%
Total:	100,0%	100,0%
Energy delivered		
LT [kWh]:	466.956	466.956
MT [kWh]:	737.868	737.859
Total [kWh]:	1.204.824	1.204.816
Average COP		
LT [-]:	5,57	1,70
MT [-]:	4,05	2,88
Total [-]:	3,01	2,27
Pumps and fans energy consumption		
LT [kWh]:	772	12.806
MT [kWh]:	32.683	17.300
Total [kWh]:	33.455	30.106
Compressor energy consumption		
LT [kWh]:	83.098	261.349
MT [kWh]:	283.935	238.789
Total [kWh]:	367.033	500.138
Total energy consumption		
LT [kWh]:	83.870	274.155
MT [kWh]:	316.618	256.089
Total [kWh]:	400.488	530.244
Savings		
Yearly energy savings [kWh]:	-	-129.756
Yearly energy savings [%]:	-	-32,4%

## 9.4 Simulation results – plot and export

On the Plots page you can investigate several results from the simulation in detail:



The meaning of each curve is explained in the dialog appearing when clicking [Help...].

If you want, you can add any of the plots you create to the report by pressing the [Add current plot to report] button.

If you double-click any of the names in the tree to the left, you can easily change the curve colour.

You should note that when you plot values, it is the mean value of that specific value within each hour that you plot:

Example (see also chapter 6.3.1):

- In one hour, the required load from the load profile is 20 kW
- The compressor pack has two stages (on/off), and the evaporation temperature is -10 °C

Capacity stages:

	Cooling capacity [kW]	Evaporation temperature [°C]	Condensation temperature [°C]
Stage 0	0	-	-
Stage 1	15	-10	35
Stage 2	30	-10	40

So, in order to get 20 kW cooling capacity within an hour in mean, we need to run 66% of the time (40 min) in Stage 1 and 33% of the time (20 min) in Stage 2.

Note that the condensation temperature will change between the two stages. The condenser stays the same, so in stage 1 the low heat load at the same ambient can be rejected at a lower condensation temperature.

When the results for this specific point are plotted, then the delivered cooling capacity is plotted as 20 kW and the condensation temperature is plotted as:  $2/3 \cdot 35^{\circ}\text{C} + 1/3 \cdot 40^{\circ}\text{C} = 36.7^{\circ}\text{C}$ .

An alternative approach could be to plot both the max and min value of the condensation temperature or plot the temperature as a stair-diagram.

If the required cooling capacity was 5 kW instead, then the system would spend 66% of the time being off – where the condensing temperature is undefined... In this case only the condensing temperature for the on-period is plotted.

This procedure is the same for all property values (temperatures, pressures, etc.) which are undefined when the system is off. The plotted energy consumption values are always weighted values as for the cooling capacity above.

#### 9.4.1 Export simulation results

If you click the [Export results] button on the Plots page, you can export all simulation results to a CSV file (Tab-delimited).

Per default, hours in which all systems are scheduled off with a month/day/hour schedule (but not ambient temperature-based scheduling), are skipped in the exports. This setting can be controlled in Options|Preferences|General.

The exported file can be imported into Microsoft Excel as follows:

- Open the exported .csv file with Microsoft Excel
- Start the import wizard from “Data > Text to Columns”
- Step 1: Select format: Delimited
- Step 2: Select delimiter: Tab
- Step 3:
  - Column date format: General.
  - Advanced:
    - Decimal separator: ‘.’
    - Thousands separator: ‘,’

#### 9.4.2 Data fields

The description of the variable names in plots and exports depends on the selected unit system, so it's best to check it from within the program. In the [Plots] window, click [Help...] to bring forward a window explaining all variables.

### 9.5 Table

The table shows the same information as the monthly energy consumption chart – the table can easily be exported to Excel using the [Export] button.

## 9.6 Warnings

If the calculation resulted in any warnings, details are shown on the warning page. Typical warnings are:

- Capacity not fulfilled – i.e., more compressor capacity is required to fulfil the load
- Operation outside envelope. Each compressor in the database has an operating envelope assigned. If the operating conditions are outside the envelope in a point, then a warning is raised... You should take care interpreting the results when the compressor is operating outside the envelope, because:
  - The models provided by the manufacturer are typically only tested inside the envelope (i.e., operation outside the envelope means extrapolating) so always check the plots of isentropic and volumetric efficiencies to see whether they take reasonable values
  - The operating point may or may not be possible with the selected compressor... Always check with the compressor manufacture whether a certain operating point is possible or whether it for example requires a different motor/oil cooling system/etc.



## 10 Results - rating points

Since Pack Calculation Pro v5.3, besides yearly energy consumption simulation, it is also possible to simulate all systems at specified operational points. This can be done in the “Rating” tab.

Depending on system configuration, different input parameters can be provided in the “Rating points inputs” table, further explained in the following paragraphs. The available input parameters are subject to change in future versions – suggestions are very welcome.

The exact same calculations as the hour-by-hour “year calculator” are performed using these rating points inputs.

Points can be added, deleted and points can be ordered by dragging and dropping a given column. The results are provided in tabbed system tables and may be exported to Excel for further analysis.

### 10.1 One-stage refrigeration systems:

The Rating points inputs and corresponding system results for example project (Example 01) are:

Rating points inputs	1	2	3	4
Ambient temperature [°C]:	0	10	20	32
MT capacity [kW]:	40	40	40	40

Subcritical Const Tc (reference)	Subcritical Var Tc	Transcritical		
<b>Main capacities</b>				
Delivered cooling capacity [kW]:	40.0	40.0	40.0	40.0
Capacity fulfilment [%]	100.0%	100.0%	100.0%	100.0%
Pack capacity [%]:	74.5%	74.5%	75.7%	95.8%
Condenser capacity [kW]:	55.8	55.8	56.3	62.8
<b>Power consumption</b>				
Main Compressor [kW]:	13.81	13.81	14.21	20.54
Condenser fan [kW]:	0.61	0.96	1.86	2.07
<b>COP</b>				
System COP (COSP) [-]:	2.77	2.71	2.49	1.77
<b>Savings</b>				
Energy saving by reference [kW]:	-	-	-	-
Energy saving by reference [%]:	-	-	-	-
<b>Additional information</b>				
Evaporation temperature [°C]:	-12.0	-12.0	-12.0	-12.0
Condensation temperature [°C]:	30.0	30.0	30.7	42.9
Heat loss compressor [kW]:	0.69	0.69	0.71	1.03
Isentropic efficiency compressor [-]:	0.64	0.64	0.64	0.65
Volumetric efficiency compressor [-]:	0.85	0.85	0.84	0.80

The cooling capacities entered here are used instead of the capacity from the (ambient temperature dependent) cooling load profiles in “Suction Side”.

In the above example, the compressor pack provides 75 % to 96 % of requested capacity. Therefore, 100 % cooling capacity is fulfilled.

## 10.2 Two-stage refrigeration systems:

The Rating points inputs and corresponding system results for example project (Example 02) are:

Rating points inputs	1	2	3	4
Ambient temperature [°C]:	0	10	20	32
LT capacity [kW]:	27.7	27.7	27.7	27.7
MT capacity [kW]:	71	71	71	71

CO2 Booster (reference)	Secondary R404A	Cascade		
<b>Main capacities</b>				
Delivered cooling capacity LT [kW]:	27.7	27.7	27.7	27.7
Delivered cooling capacity MT [kW]:	71.0	71.0	71.0	61.2
Capacity fulfilment LT [%]	100.0%	100.0%	100.0%	100.0%
Capacity fulfilment MT [%]	100.0%	100.0%	100.0%	90.6%
Pack capacity LT [%]:	76.3%	76.3%	76.3%	76.3%
Pack capacity MT [%]:	66.6%	74.8%	92.5%	100.0%
Gas cooler capacity [kW]:	124.5	132.2	146.2	149.1
<b>Power consumption</b>				
Compressor LT [kW]:	5.19	5.19	5.19	5.19
Compressor MT [kW]:	17.26	25.28	40.04	53.75
Condenser fan [kW]:	1.93	2.54	3.42	3.42
<b>System COP (COSP)</b>				
LT [-]:	5.34	5.34	5.34	5.34
MT [-]:	5.46	3.76	2.41	1.66
Total [-]:	4.05	2.99	2.03	1.43
<b>Savings</b>				
Energy saving by reference [kW]:	-	-	-	-
Energy saving by reference [%]:	-	-	-	-
<b>Additional information</b>				
Evaporation temperature LT [°C]:	-30.0	-30.0	-30.0	-30.0
Evaporation temperature MT [°C]:	-10.0	-10.0	-10.0	-10.0
Intermediate temperature [°C]:	-4.0	-4.0	-4.0	-4.0
Gas cooler pressure [bar]:	45.0	54.8	67.5	86.1
Heat loss LT compressor [kW]:	0.26	0.26	0.26	0.26
Heat loss MT compressor [kW]:	0.86	1.26	2.00	2.69
Isentropic efficiency LT compressor [-]:	0.60	0.60	0.60	0.60
Isentropic efficiency MT compressor [-]:	0.64	0.68	0.68	0.66
Volumetric efficiency LT compressor [-]:	0.88	0.88	0.88	0.88
Volumetric efficiency MT compressor [-]:	0.90	0.87	0.82	0.75

In this case, the compressor pack of the “CO2 Booster system“ is not able to provide enough cooling capacity for the medium temperature capacity at 32°C ambient.

If both a two-stage and a one-stage refrigeration system are compared, then the MT capacity will be ignored by the one-stage system, i.e., it only uses the LT capacity as cooling capacity.

In two-stage systems, at least one of the capacities must be above zero.

### 10.3 Ambient temperature and different condenser types

The ambient temperature for air-cooled condenser, dry cooler, evaporative condenser, cooling tower and hybrid cooler refers to the dry bulb temperature. In case humid air calculations are necessary (evaporative condenser, cooling tower, hybrid cooler), the relative humidity will appear as an additional rating point input:

Rating points inputs	1	2	3	4
Ambient temperature [°C]:	0	10	20	32
Relative humidity [%]:	50	50	50	50
MT capacity [kW]:	40	40	40	40

The wet bulb temperature is in that case calculated from dry bulb temperature and relative humidity.

If the water-cooled condenser is used, the ambient temperature refers to the water temperature.

## 10.4 Heating systems

The Rating points inputs for heat pump cycles are ambient temperature, supply temperature and heating capacity.

Rating points inputs (heat pump)	1	2	3	4
Ambient temperature [°C]:	-12	-6	0	6
Supply temperature [°C]:	30	30	30	30
Heating capacity [kW]:	15	15	15	15

In example project file “Example 03 – Heat pumps”, the results for the air source system are:

Air source (reference)	Ground source			
<b>Main capacities</b>				
Delivered heating capacity [kW]:	30,0	30,0	30,0	30,0
Capacity fulfilment [%]:	100,0%	100,0%	100,0%	100,0%
Pack capacity [%]:	92,5%	78,0%	66,8%	58,1%
Cooling capacity [kW]:	20,1	20,6	21,1	21,6
<b>Power consumption</b>				
Main Compressor [kW]:	8,37	7,89	7,46	7,05
Condenser pump [kW]:	0,00	0,00	0,00	0,00
Evaporator fan [kW]:	1,04	0,87	0,75	0,65
<b>COP</b>				
System COP (COSP) [-]:	3,19	3,42	3,66	3,89
<b>Savings</b>				
Energy saving by reference [kW]:	-	-	-	-
Energy saving by reference [%]:	-	-	-	-
<b>Additional information</b>				
Evaporation temperature [°C]:	-20,7	-16,6	-12,7	-8,9
Condensation temperature [°C]:	33,2	33,8	34,5	35,2
Heat loss compressor [kW]:	0,42	0,39	0,37	0,35
Isentropic efficiency compressor [-]:	0,65	0,64	0,63	0,62
Volumetric efficiency compressor [-]:	0,84	0,86	0,87	0,88

## 10.5 Warnings

If the calculations resulted in any warnings, details are shown in the rating points warning frame next to the inputs and results tables.


## 11 Economy

On the economy page you can calculate life cycle costs, payback time and CO<sub>2</sub>-equivalent emissions.

### 11.1 Energy prices

Before calculating life cycle costs and/or CO<sub>2</sub>e-emissions, some values should be provided:

- The currency used (this is just a text – there is no currency conversion included in PackCalc)
- The expected average electricity costs – i.e., the expected average energy costs in the lifetime of the system
- Equivalent CO<sub>2</sub> release from electricity production. This number will depend very much on your location! This is used to calculate indirect emissions, i.e., emissions due to the power consumption of your system.
- Equivalent CO<sub>2</sub> release and expected average energy costs for direct combustion of different fuel types in a backup boiler.

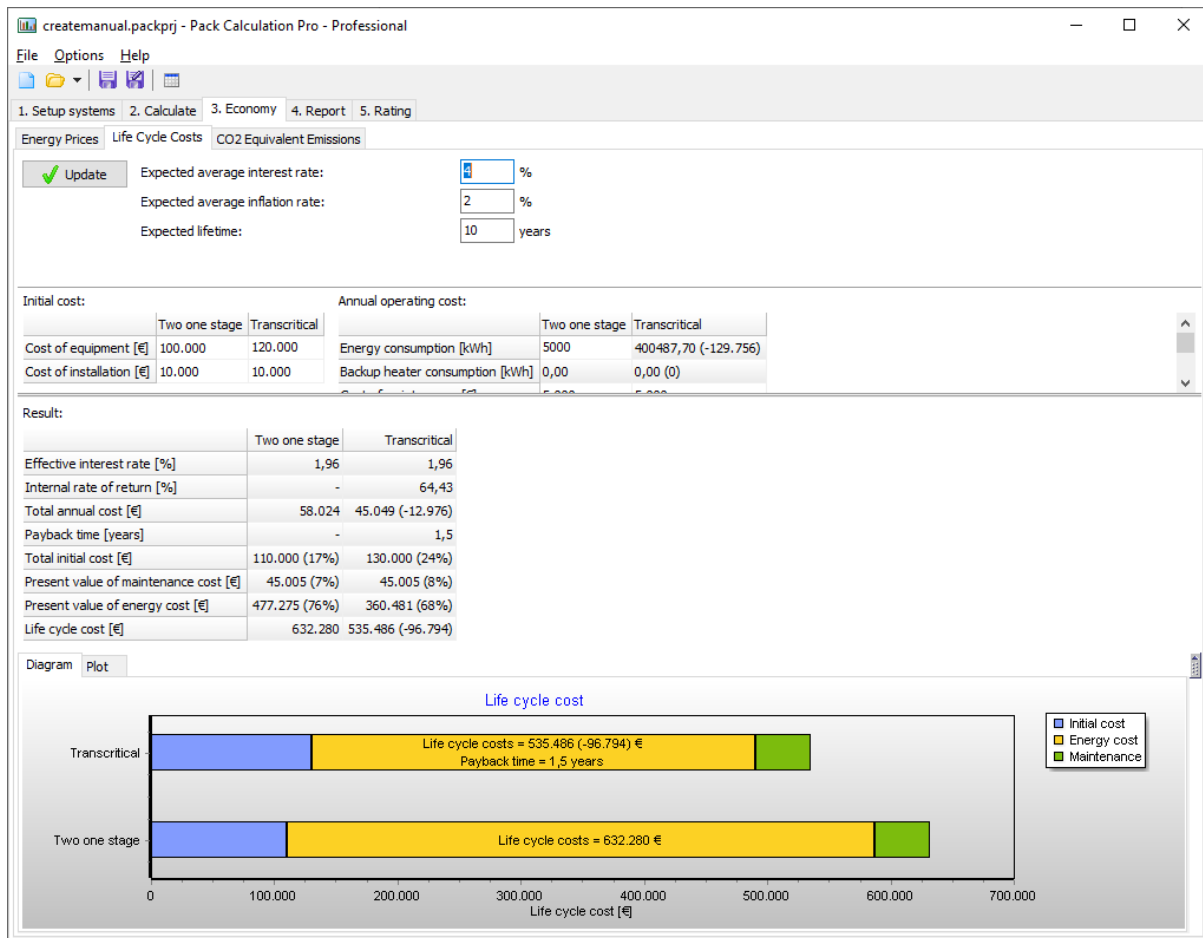
Energy Prices	Life Cycle Costs	CO2 Equivalent Emissions
Currency:		
€		
Electricity		
CO2 release, electricity:	0,530	kg/kWh
Expected average electricity cost:	0,1	€/kWh
Gas boiler		
CO2 release, gas:	0,201	kg/kWh
Expected average gas cost:	0,1	€/kWh
Liquid / oil boiler		
CO2 release, oil:	0,279	kg/kWh
Expected average oil cost:	0,1	€/kWh
Solid fuel / wood boiler		
CO2 release, solid fuel:	0,395	kg/kWh
Expected average solid fuel cost:	0,1	€/kWh

### 11.2 Life cycle costs (LCC)

For life cycle costs, the following additional values should be provided:

- The expected average interest rate – i.e., the expected average interest rate in the lifetime of the system
- The expected average inflation rate – i.e., the expected average inflation rate in the lifetime of the system
- The lifetime of the system in years.

You also need to specify the costs of the system – both initial costs and the maintenance costs. The energy costs are automatically included:



When ready, press the [Update] button and the program will calculate the following values:

- **Effective interest rate [%]:** The effective interest rate based on the given interest rate and the inflation:

$$\text{Effective interest rate, } r_{\text{eff}} = \frac{(\text{Interest rate} - \text{Inflation})}{1 + \text{Inflation}}$$

- **Internal rate of return [%]:** The interest rate you would have to get in a bank (or from another investment) if you placed your money there instead of using them to improve your system
- **Total annual costs:** Total cost of energy and maintenance
- **Total initial costs:** Total cost of equipment and installation
- **Present value of maintenance costs:** Estimate of the future maintenance costs in present day money
- **Present value of energy costs:** Estimate of the future energy costs in present day money
- **Life cycle costs:** The sum of **Total initial costs**, **Present value of maintenance costs** and **Present value of energy costs**.

The present value of a certain amount is calculated as:

$$Present\ value = PWF \cdot Amount$$

$$PWF = \frac{(1 + r_{eff})^{Lifetime} - 1}{r_{eff} \cdot (1 + r_{eff})^{Lifetime}}$$

The payback time calculated of a given system is a simple payback time calculated as:

$$Payback = \frac{Initial\ costs_{system} - Initial\ costs_{reference\ system}}{Annual\ costs_{reference\ system} - Annual\ costs_{system}}$$

Note that the payback time is always relative to the reference system (i.e. the payback time will change according to your choice of reference system).

### 11.3 Cooling tower water consumption

If one of the systems you are comparing is using a cooling tower as condenser, you can include water consumption if the economy calculation.

If at least one system has a cooling tower, the [Cooling tower economy] button will appear on the economy page:

Currency: €	Expected average interest rate: 4 %	Expected average inflation rate: 2 %	<input type="button" value="Update"/>	Detailed cooling tower economy
Expected average energy cost: 0.1 €/kWh	Expected lifetime: 10 years	Select system with cooling tower: Two one stage		<input type="button" value="Cooling tower economy..."/>

First you select which cooling tower you want to include (you could have more than one system using a cooling tower), and then press the [Cooling tower economy] button:

**Cooling Tower water consumption** Prices    Precipitation data

**Water consumption rates:**

Recharging loss (in percent of softened water):  %

Bleed off water (in percent of makeup water):  %

Windage loss (in percent of circulating water):  %

**Precipitation:**

Location:

Roof area:  m<sup>2</sup>

**Rainwater tank sizes to calculate:**

Number of tanks:

Maximum size:  m<sup>3</sup> Update

**Economy**    Details for selected rainwater tank    Monthly water balance sheet

Tank size [m <sup>3</sup> ]	Investment costs [€]	Operating costs [€]	Total Present value [€]
2	2,000	38,000	40,000
4	3,000	37,000	40,000
6	4,000	36,000	40,000
8	5,000	35,000	40,000
10	6,000	34,000	40,000
12	7,000	33,000	40,000
14	8,000	32,000	40,000
16	9,000	31,000	40,000
18	10,000	30,000	40,000
20	11,000	29,000	40,000
22	12,000	28,000	40,000
24	13,000	27,000	40,000
26	14,000	26,000	40,000
28	15,000	25,000	40,000
30	16,000	24,000	40,000

Legend:

- Investment costs
- Operating costs
- Selected tank investment costs
- Selected tank operating costs

**Selected rainwater tank size: 4 m<sup>3</sup>** OK    Cancel

On the first page you specify details about the water consumption (referring to the drawing), the location (if you are using a rainwater tank) and the area of the roof used to collect rainwater.

In the plot, the program tries to show the most economic choice of rainwater tank, based on tank prices and prices of raw water as defined on page two:



Cooling Tower water consumption

Cooling tower water consumption Prices Precipitation data

Prices not related to water treatment:

Installation cost: € 10,000.00

Equipment cost: € 100,000.00

Yearly maintenance cost: € 5,000.00

These prices should include refrigeration system, cooling tower, pumps, fans etc. but not rainwater tank!

These prices will be added to the water treatment prices when returning to the main LCC calculation.

Water treatment prices:

Water supply: 2 €/m<sup>3</sup>

Salt for water softener: 0.2 €/m<sup>3</sup> softened water

Chemicals: 1 €/m<sup>3</sup> makeup water

Drainage fee: 4 €/m<sup>3</sup>

Drainage fee includes only bleed off and recharging loss (i.e. no fee for evaporated water and windage loss)

Rainwater tank price function (incl. installation):

From [m <sup>3</sup> ]	To [m <sup>3</sup> ]	Price [€/m <sup>3</sup> ]
0	30	460
31	80	410
81	160	340
161	100000	280

Selected rainwater tank size: 4 m<sup>3</sup>

OK Cancel

Note that the installation costs, equipment costs and maintenance costs you enter on this page, also includes the complete refrigeration system - including everything except the rainwater tank. So, if you use this tool for calculating economy related to cooling tower water consumption, then you should not change the costs on the main economy page but only in this dialog (the values on the main economy page will automatically include the rain water tank and water costs).

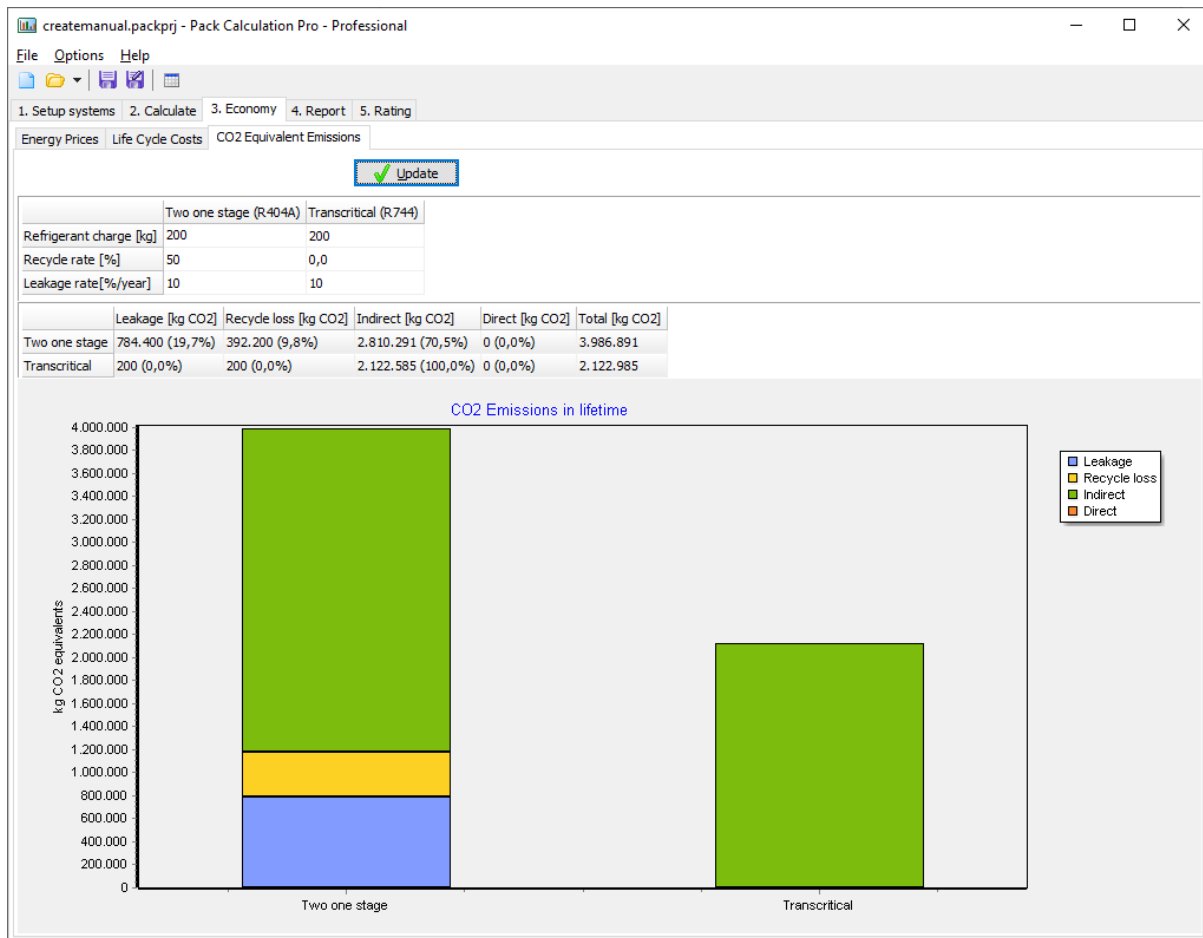
Note also that the default prices for water and rainwater tanks are in DKK (the prices shown above reflect approximate Danish prices in €). Note also that you can optionally include drainage fee for all the water that the cooling tower uses (this is sometimes the case) or only include drainage fee for bleed off and recharging loss.

## 11.4 CO<sub>2</sub> emissions (TEWI)

On the "CO<sub>2</sub> equivalent emissions" page you can calculate the CO<sub>2</sub>-equivalent emissions for the systems you have defined. The calculation depends on the details filled out under Energy Prices (section 11.1) and the following input:

- The refrigerant charge – this is used to calculate equivalent CO<sub>2</sub> emissions due to release of refrigerant (CO<sub>2</sub>e calculated using GWP<sub>100</sub> values for all supported refrigerants):
  - Recycle rate, which equals the percentage of the charge which is recycled when the system is decommissioned.
  - Leakage rate, which is the percentage of the charge that is leaked to the ambient every year.

The CO<sub>2</sub> emissions in the lifetime of a system could look like this:



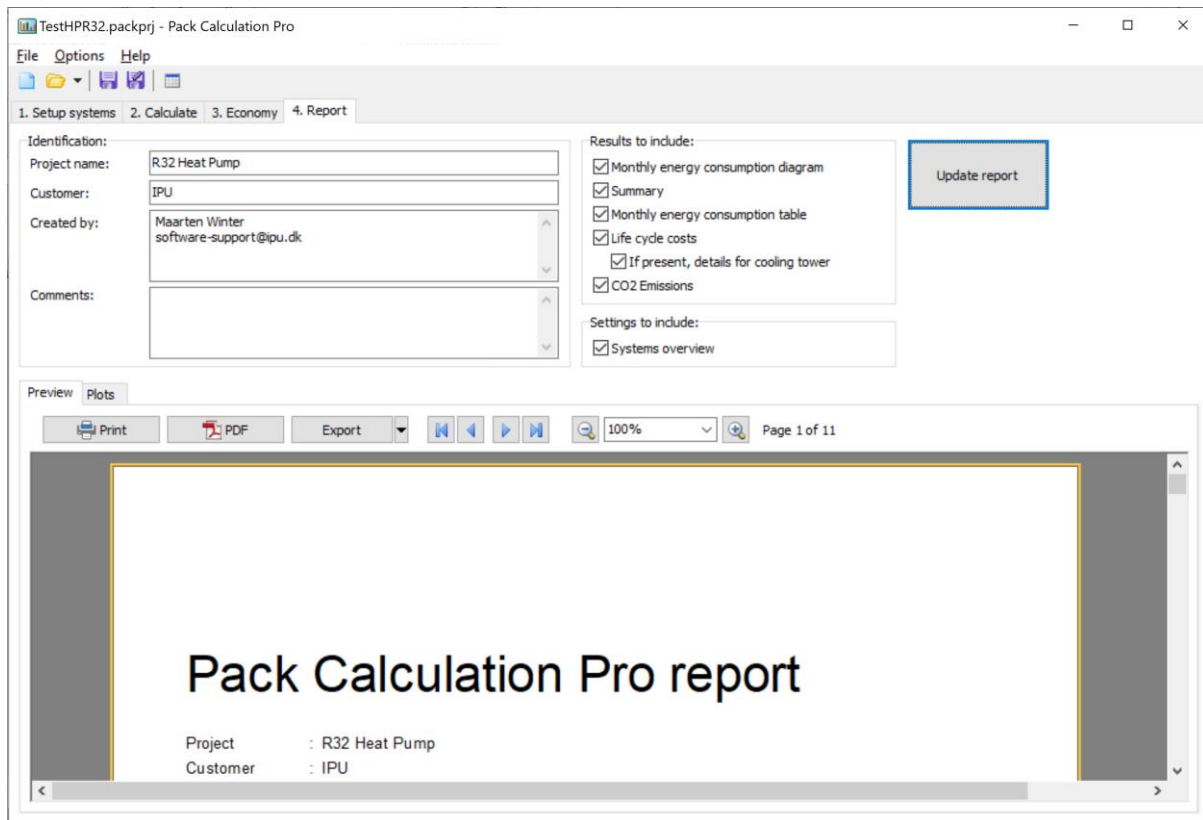
The graph divides the emission into:

- Leakage.
- Recycle loss.
- Indirect (due to power consumption of the system).

In the above example, the indirect emissions are dominant, while the contribution from leakage and recycle loss is only important for the R404A systems, and not for the transcritical systems using CO<sub>2</sub> as refrigerant.

## 12 Report

When you have made simulations and economic calculations you can export to a PDF or Microsoft Word® report:



The information that goes into the report is contains all relevant tables from the Calculate and Economy steps of the calculation, and any custom plots you have added – see chapter 9.4.

If you use a personal or academic license, the report will be watermarked, while if you have a professional license, you have the possibility to automatically include company logo etc. (see chapter 13).

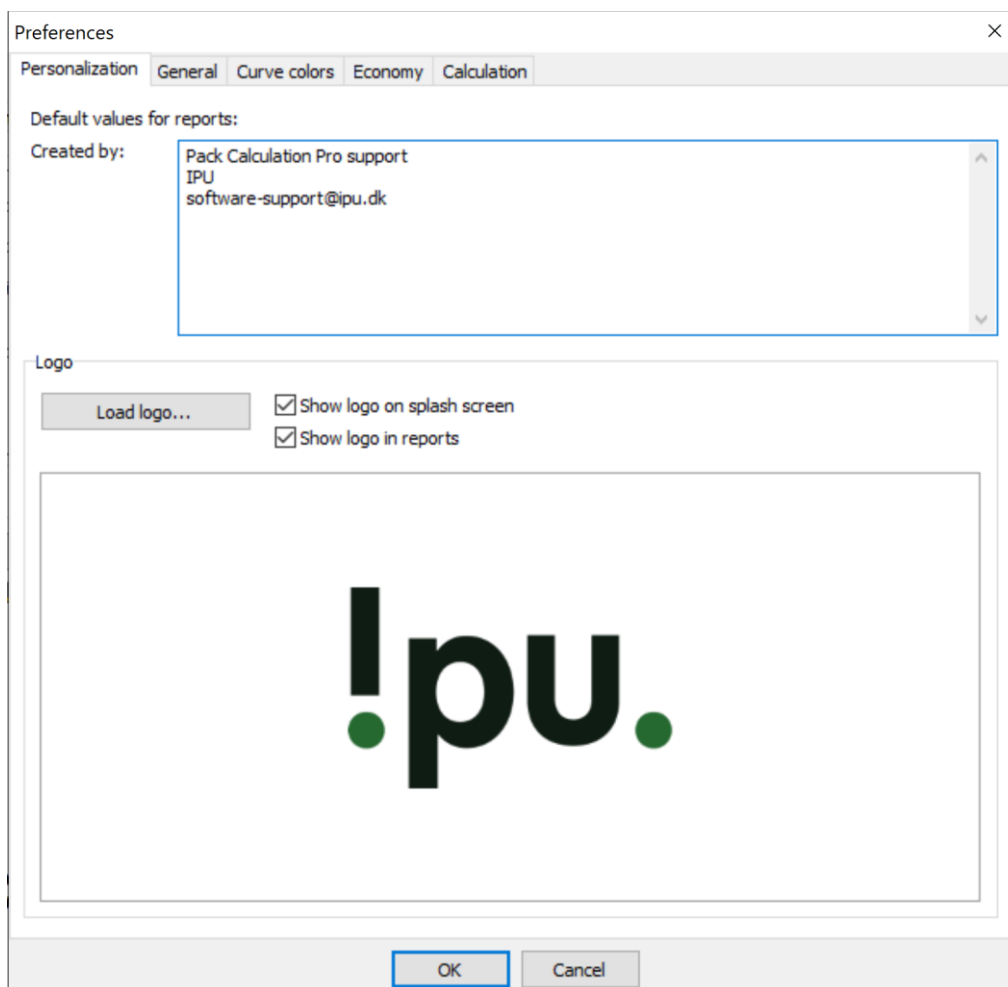
## 13 Options, preferences, and units

In the options menu you have the following possibilities:

- **Show/Hide overview.** Selecting this will give an overview of all the systems and values you have defined. It enables you to compare the systems and find differences in setup that might cause differences in the simulation results. When the Overview is shown, you have to select the menu again to hide the overview.
- **Preferences** – see below.
- **Units** – see below.
- **Language.** Enables you to change the language in Pack Calculation Pro. When the language selection dialog is displayed, you will see a list of installed languages, and to what percentage the translation is completed. If you cannot find your own language, you are welcome to make a translation – see the Pack Calculation Pro homepage for details. Also check the homepage for language updates.'

### 13.1 Preferences

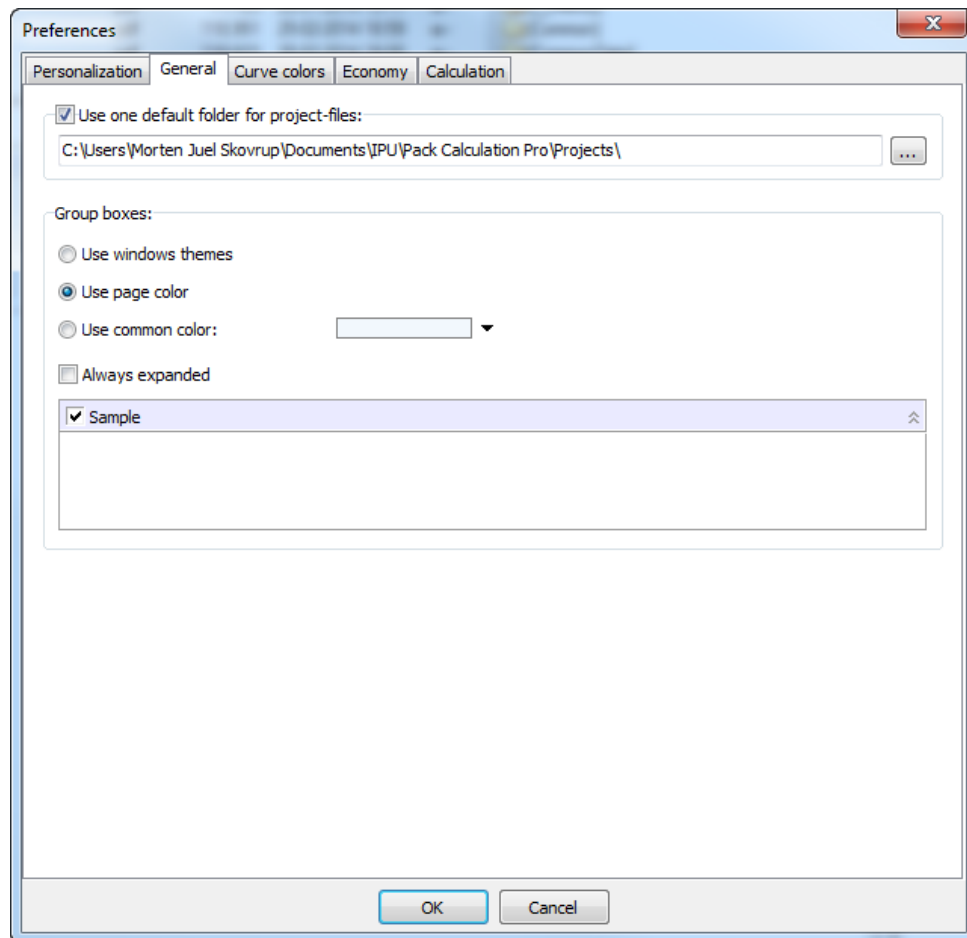
When you select the Options|Preferences menu, the following dialog appears:



The first page – Personalization – is only available if you have a professional license. The options on the Personalization page enables you define default logos to your reports – including a custom logo.

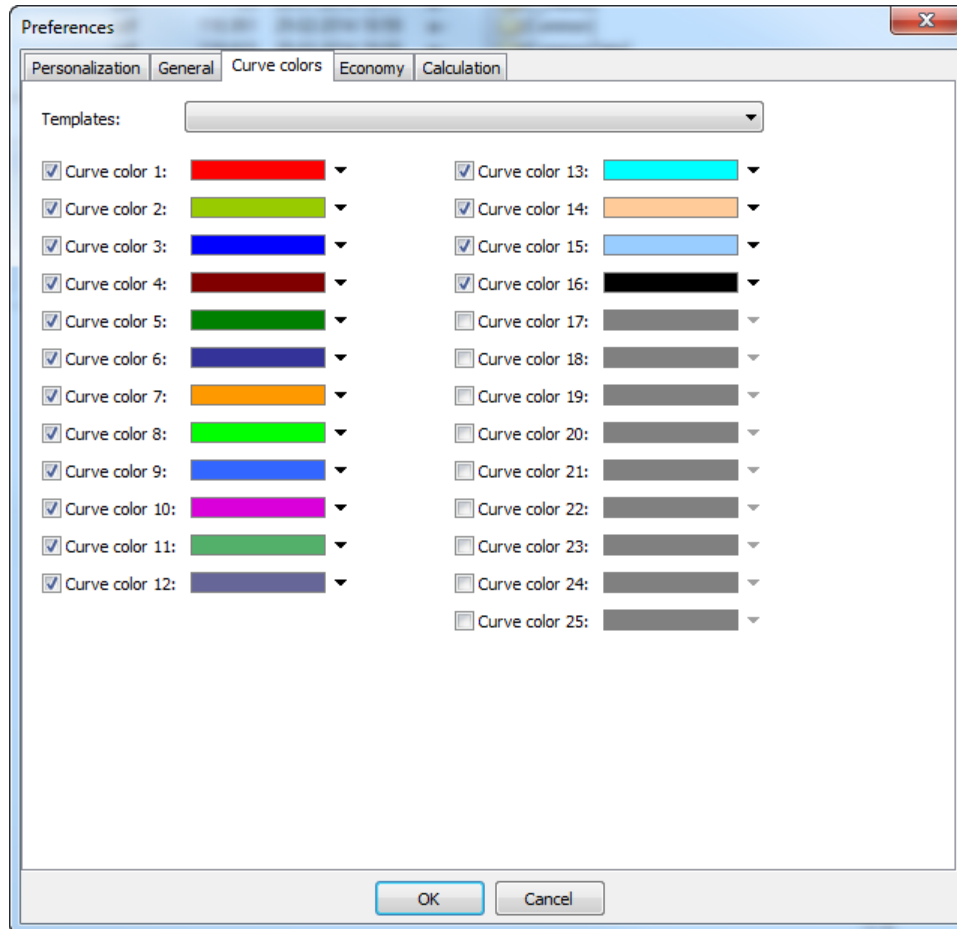
### 13.1.1 General

The general page looks like this:



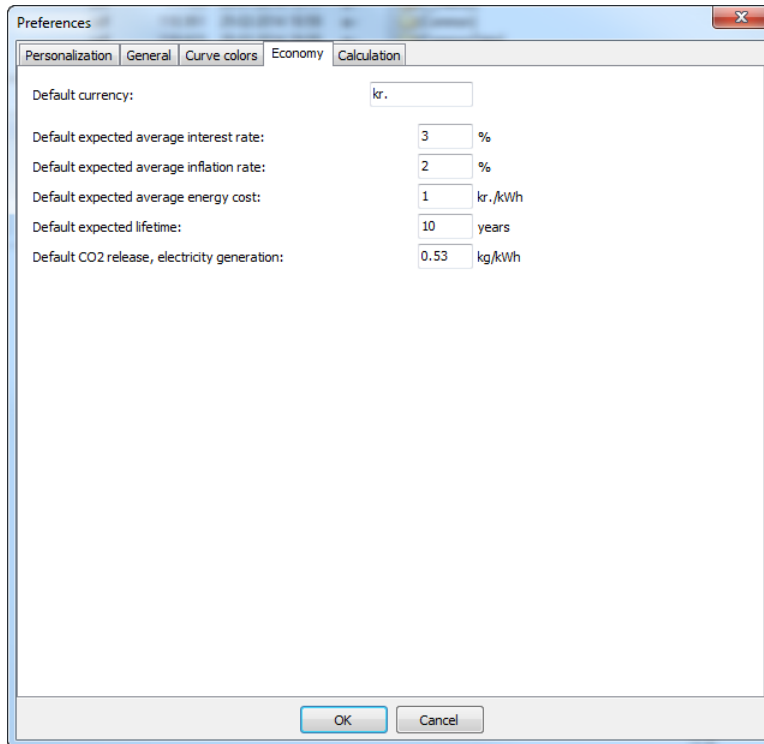
Here you can specify the default location on your projects, and what the different elements in Pack Calculation Pro shall look like – try changing the options and see the effect on the pages where your system is defined.

### 13.1.2 Curve colors



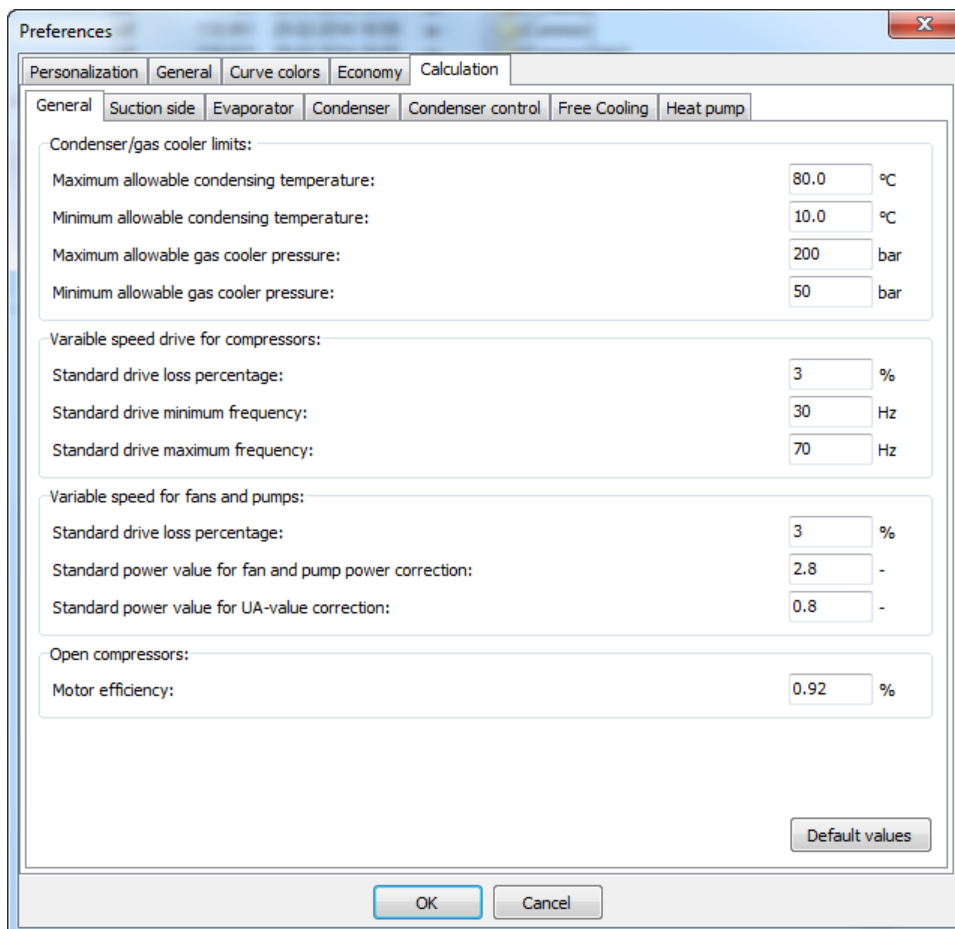
On the curve colors page you can select the colors of the curves on the plot shown on the Calculate|Plots page. There are several templates you can select between, but you can also define your own colors. The first curves curve on the plot get curve color 1, the second color 2 etc. The colors repeat from 1 again if there are more curves on the plot than there are colors.

### 13.1.3 Economy



On the economy page you set default values for the economy calculations.

### 13.1.4 Calculation



On the calculation page and subpages, you can see and change all the default values used in Pack Calculation Pro. Most of the settings have to do with how PackCalc automatically selects the size of heat exchangers, but there is also values directly related to the calculation (for example will the power consumption of open compressor always be divided by the motor efficiency displayed above).

You can always get back to the default values, using one of the buttons that are located on each page, and the meaning of most of the default values are explained throughout this guide.

## 13.2 Units

When you select the Preferences | Units menu you get a submenu where you can select between European, American, SI or Custom units. If you select Custom units, it will bring up the following dialog, where you can also see the consequences of selecting the European, American or SI menu items – they are represented by the buttons on the right side of the dialog:

The 'Units' dialog box contains the following settings:

- Temperature: degree Celsius [°C]
- Temperature difference: Kelvin [K]
- Pressure: Bar [bar]
- Pressure drop: Bar [bar]
- Cooling capacity: Kilowatt [kW]
- Heating capacity: Kilowatt [kW]
- Power: Kilowatt [kW]
- Energy: Kilowatt hour [kWh]
- Mass: Kilograms [kg]
- Volume: Cubic meters [m<sup>3</sup>]
- Area: Square meters [m<sup>2</sup>]
- Mass flow: Kilogram per hour [kg/h]
- Volume flow: Cubic meter per hour [m<sup>3</sup>/h]

Buttons on the right: European (selected), American, SI.

Power supply:  50 Hz,  60 Hz

Coefficient of performance:  Use COP,  Use EER

Buttons at the bottom: OK, Cancel

Besides selecting units, you also select which power supply frequency should be the default when selecting compressors from the database.

Lastly, you can select whether you wish to use COP<sub>R</sub> [W/W] or EER [BTU/Wh] (see AHRI Standard 550/590) to describe cooling energy efficiency. NOTE: Ignored for heat pump calculations.

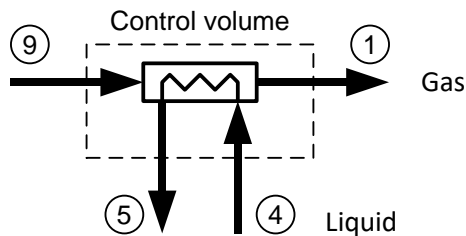
When/if you change units, all values will automatically change in Pack Calculation Pro – except the simulation results. To update the simulation results to new units, you must calculate again.



## A Heat exchanger efficiency

The efficiency for an internal heat exchanger can be defined as:

$$\varepsilon = \frac{\dot{Q}_{ihx}}{\dot{Q}_{ihx,max}} \quad (1)$$

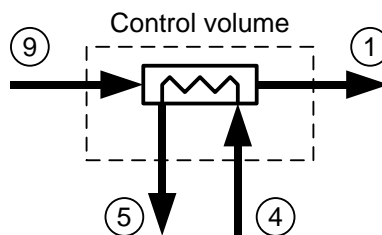


The maximum heat that can be transferred to the gas, is equal to the case where the gas is heated to the temperature  $T_4$ :

$$\varepsilon = \frac{\dot{m} \cdot c_{p,gas} \cdot (T_1 - T_9)}{\dot{m} \cdot c_{p,gas} \cdot (T_4 - T_9)} = \frac{T_1 - T_9}{T_4 - T_9} \quad (2)$$

Sometimes it can give numerical problems using the temperature efficiency defined in (2). If you for example have a model where you cannot find the temperatures in point 4 and 9 explicitly, then the model might have problems if guesses on the temperature in point 9 falls within the two phase area...

In such a case you can define the efficiency based on enthalpies instead of temperatures:



We still have that the efficiency equals:

$$\varepsilon = \frac{\dot{Q}_{ihx}}{\dot{Q}_{ihx,max}} \quad (3)$$

And it can be written using enthalpies as:

$$\varepsilon = \frac{\dot{m} \cdot (h_1 - h_9)}{\dot{m} \cdot (h_{1,max} - h_9)} = \frac{h_1 - h_9}{h_{1,max} - h_9} \quad (4)$$

Where  $h_{1,\max}$  is the enthalpy the gas would have in point 1 if it was heated to the temperature  $T_4$ .

That is,  $h_{1,\max}$  is the enthalpy of the gas found at pressure  $P_1$  but at the temperature  $T_4$ :

$$h_{1,\max} = \text{Enthalpy}('Fluid', P = P_1, T = T_4) \quad (5)$$

The formulation in (4) is used throughout the program.

## B Condenser models

For each condenser type, you can let the program automatically select a condenser size, or you can specify the condenser size yourself. If you specify the size yourself, then the parameters available depends on the condenser type. But first a general overview of the condenser models used in the program.

In general the condenser model can be expressed as:

$$\dot{Q}_c = O \cdot A \cdot \Delta P \quad (6)$$

Where:

$\dot{Q}_c$	Is condenser capacity
$O$	Is a generalized overall "transfer coefficient" (heat or mass)
$A$	Is an area
$\Delta P$	Is a difference in driving potential.

For an air cooled condenser equation (6) normally reads:

$$\dot{Q}_c = U \cdot A \cdot \Delta T \quad (7)$$

While for a cooling tower (and evaporative condenser) equation (6) equals:

$$\dot{Q}_c = \sigma \cdot A \cdot \Delta I \quad (8)$$

In the equations above:

$U$	Is the overall heat transfer coefficient
$\Delta T$	Is a temperature difference (temperature is the driving potential)
$\sigma$	Is a combined heat and mass transfer coefficient
$\Delta I$	Is an enthalpy difference (humid air)

$\Delta T$  for an air cooled condenser is chosen as the difference between the condensation temperature and the air inlet temperature:

$$\Delta T = T_c - T_{air,in} \quad (9)$$

For a cooling tower  $\Delta I$  is selected as:

$$\Delta I = I_{s12} - I_1 \quad (10)$$

Where:

$I_{s12}$	is the saturated enthalpy of humid air taken at the mean temperature of the water: $T_{wm} = (T_{w,in} + T_{w,out})/2$
$I_1$	is the enthalpy of humid air at condenser inlet

For an evaporative condenser  $\Delta I$  is chosen as:

$$\Delta I = I_c - I_1 \quad (11)$$

Where:

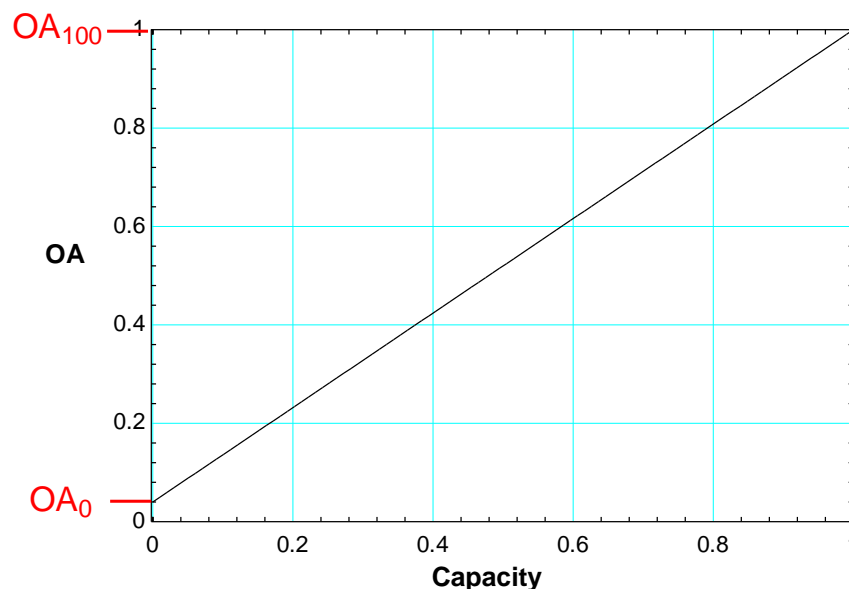
$I_c$  is the saturated enthalpy of humid air taken at the condensation temperature.

It is assumed that the overall transfer coefficient is not dependent on the size of the driving potential. In other words it is assumed that neither  $U$  nor  $\sigma$  is a function of temperature or humidity.

This means that if you know  $U$  (or  $\sigma$ ) in a dimensioning condition, you can relatively easily find the capacity of fans (and/or pumps) that will give you a wanted value of  $U$  (or  $\sigma$ ), and from the capacity you can calculate the power consumption of the fans (and/or pumps).

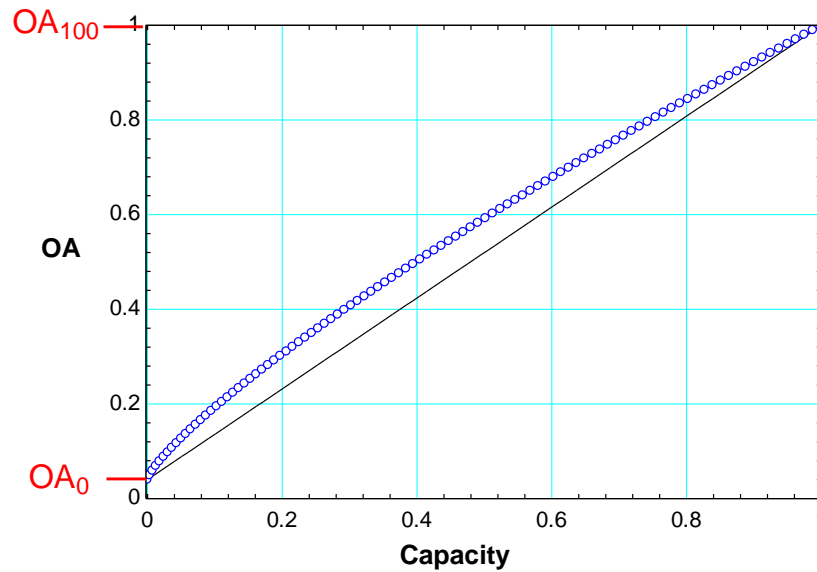
Even though the capacity of the equipment is 0 (fans and pumps turned off) a condenser will typically have some condenser capacity. In case of an air cooled condenser for example, air will still flow through the condenser by natural convection even though the fans are turned off.

If the capacity control of the condenser is done by switching fans on and off, the relationship between  $OA$  and the capacity can be illustrated like this:



The graph illustrates that by switching fans on and off, you really don't change the overall transfer coefficient  $O$ , but rather the area  $A$ .

If the fans (and pumps) on the other hand are speed controlled you normally control all fans on a condenser – i.e. when you increase the capacity you do not increase the area but rather the overall transfer coefficient. When the transfer coefficient changes, the relation between capacity and  $OA$  is no longer linear – you get a slightly better  $OA$  value for the same capacity as illustrated by the blue curve:



The two values  $OA_0$  and  $OA_{100}$  can be found from the dimensioning condition.

In the program the condenser capacity at a certain condition is given, because:

- the load profile is specified
- the evaporation temperature is specified
- the condensation temperature is specified (given by the selected control algorithm).

And then you can calculate the refrigerant mass flow, compressor capacity and thus condenser capacity.

When you know the condenser capacity and the conditions (for example ambient and condensation temperature), you can calculate the needed  $OA$  value:

$$OA = \frac{\dot{Q}_c}{\Delta P} \quad (12)$$

If the relation between capacity and  $OA$  is linear, the needed capacity can be found from:

$$Cap = \frac{OA - OA_0}{OA_{100} - OA_0} \quad (13)$$

This comes directly from the plots above.

If the equipment is speed controlled, the capacity can be found from:

$$Cap = \left( \frac{OA - OA_0}{OA_{100} - OA_0} \right)^{\frac{1}{n}} \quad (14)$$

Where  $n$  typically is around 0.8.

When the capacity is known, the power consumption of the condenser fans (and pumps) can be calculated. If fans (and pumps) are not speed controlled the power consumption will be:

$$\dot{W}_c = Cap \cdot \dot{W}_{c,100} \quad (15)$$

Where:

$\dot{W}_{c,100}$  is the power consumption at 100% capacity ( $Cap = 1$ )

If fans (and pumps) are speed controlled, the power consumption is:

$$\dot{W}_c = Cap^m \cdot \dot{W}_{c,100} \quad (16)$$

Where  $m$  typically is around 2.8.

So to sum up:

In the design condition you know the following:

- Condenser capacity at  $Cap = 1$ ,  $\dot{Q}_{c100,nom}$
- Difference in driving potential (temperature or enthalpy) at  $Cap = 1$ ,  $\Delta P_{100,Nom}$
- Condenser capacity at  $Cap = 0$ ,  $\dot{Q}_{c0,nom}$
- Difference in driving potential (temperature or enthalpy) at  $Cap = 0$ ,  $\Delta P_{0,Nom}$
- Power consumption of equipment at  $Cap = 1$ ,  $\dot{W}_{c,100}$

Then  $OA_{100}$  and  $OA_0$  can be found.

At a given condition the condenser capacity is known and then  $OA$  can be found:

$$OA = \frac{\dot{Q}_c}{\Delta P} \quad (17)$$

When  $OA$  is known the necessary capacity can be found:

$$Cap = \left( \frac{OA - OA_0}{OA_{100} - OA_0} \right)^{\frac{1}{n}} \quad (18)$$

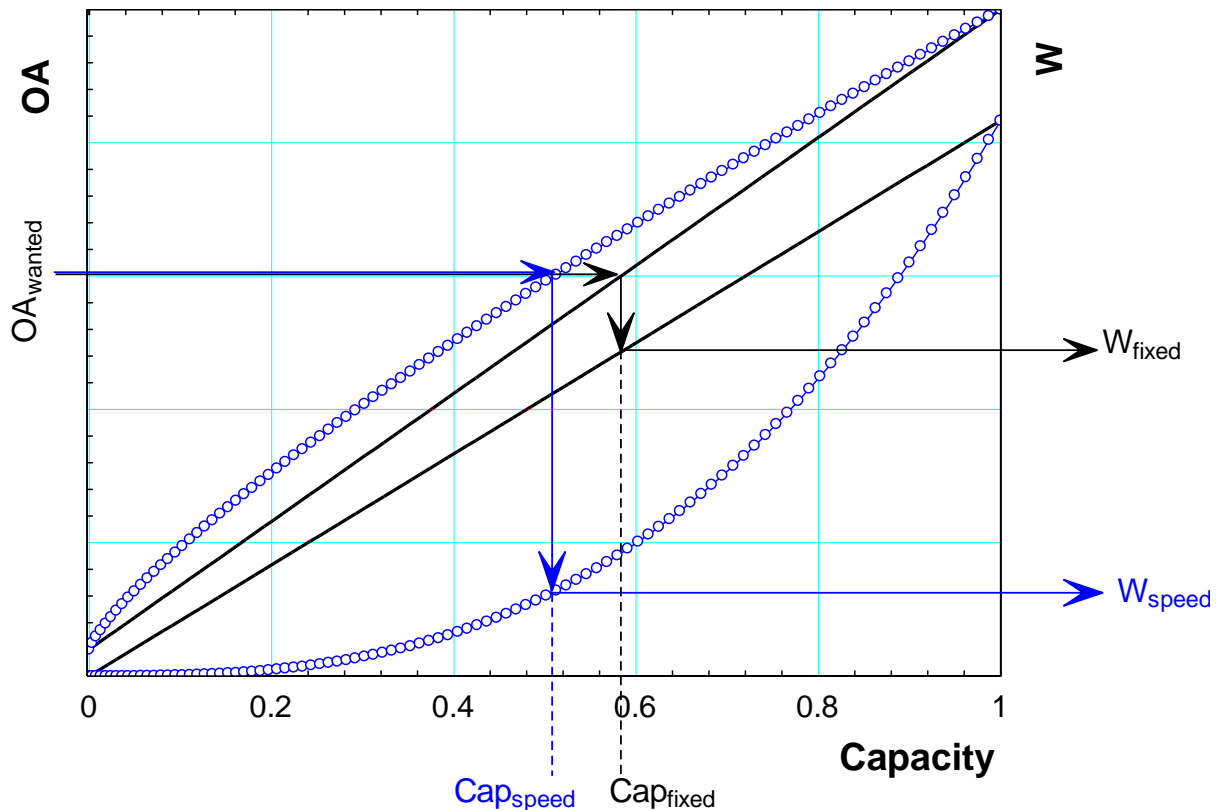
Where  $n = 0.8$  if the equipment is speed controlled else  $n = 1$ .

When the capacity is known, the power consumption can be found from:

$$\dot{W}_c = Cap^m \cdot \dot{W}_{c,100} \quad (19)$$

Where  $m = 2.8$  if the equipment is speed controlled else  $m = 1$ .

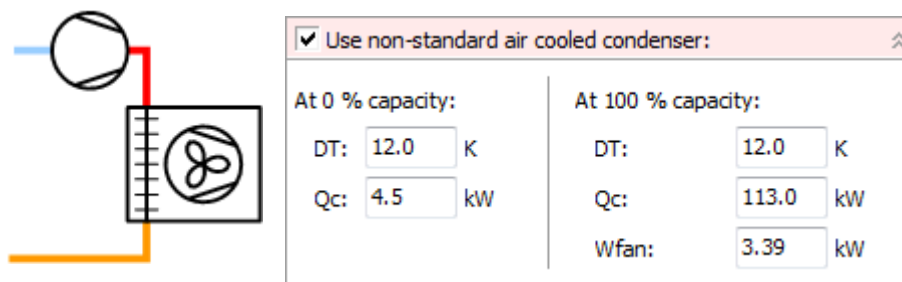
The procedure is illustrated below:



When you specify the size of the condenser in the program, you actually specify  $OA_{100}$  and  $OA_0$ .

For the different condenser models in the program, this specification is slightly different.

## B.1 Air cooled condenser or gas cooler



For the air-cooled condenser, you can change the following values:

At 100% capacity:

- **DT.** Dimensioning temperature difference. Default value is 12 K.
- **Qc.** Dimensioning condenser capacity. Default value equals the condenser capacity of the selected compressors in the selected dimensioning state.
- **Wfan.** Power consumption of the fans at 100% condenser capacity. Default value is 3% of the dimensioning Qc.

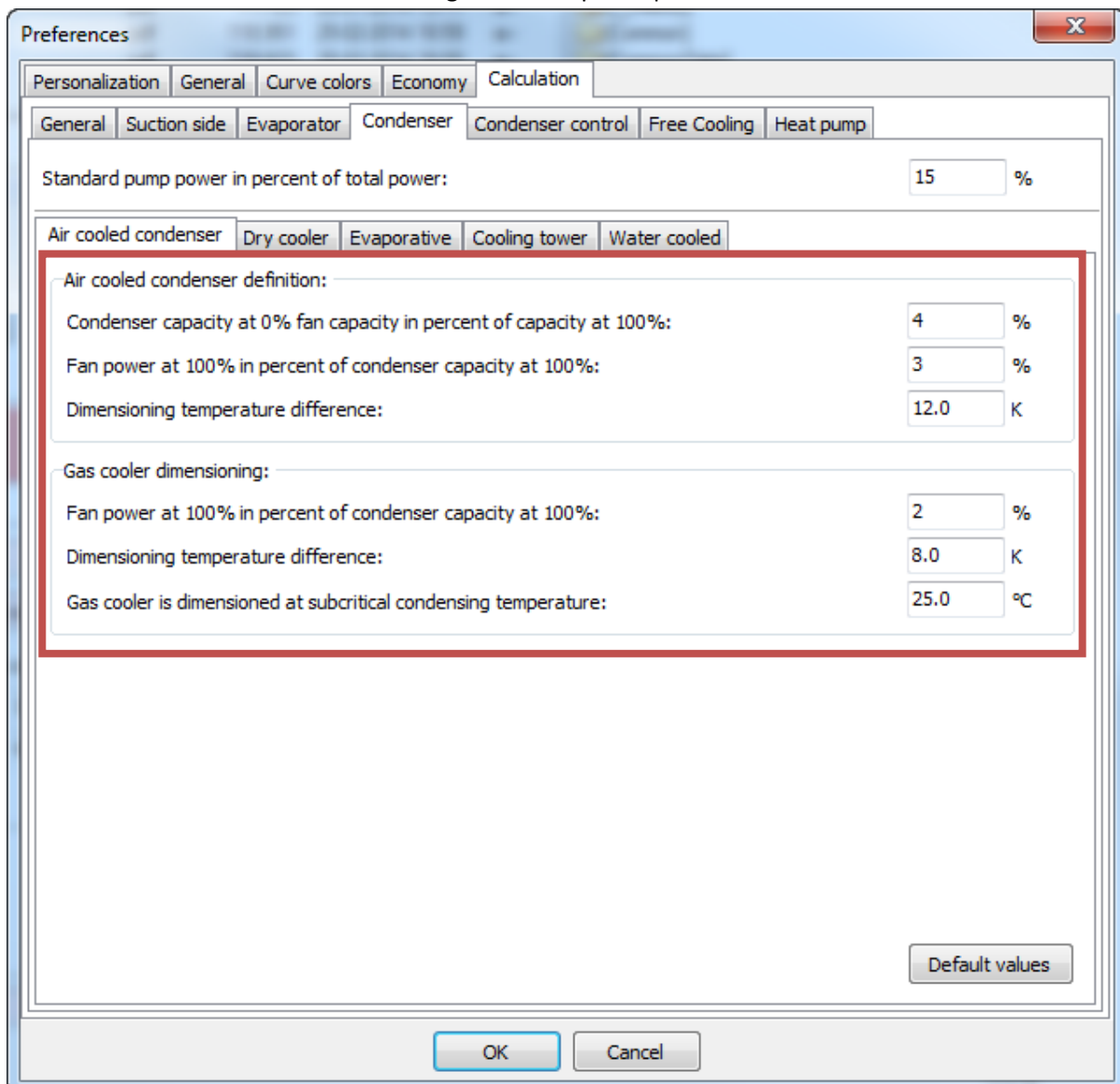
At 0% capacity:

- **DT.** Dimensioning temperature difference. Default value is 12 K.
- **Qc.** Dimensioning condenser capacity. Default value equals 4% of Qc at 100% capacity.

If you instead have a transcritical system, the settings are the same (the gas cooler is dimensioned as a condenser), except that the default values are different:

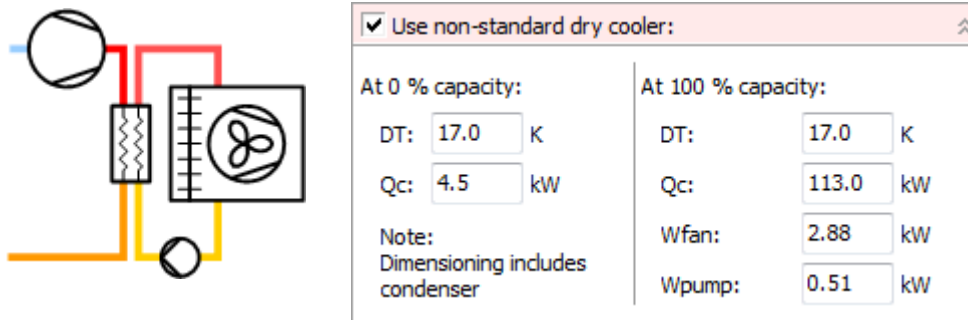
- **DT.** Dimensioning temperature difference. Default value is 8 K.
- **Wfan.** Power consumption of the fans at 100% condenser capacity. Default value is 2% of the dimensioning Qc.

Note that all default values can be changed in the Options|Preferences menu:





## B.2 Dry cooler



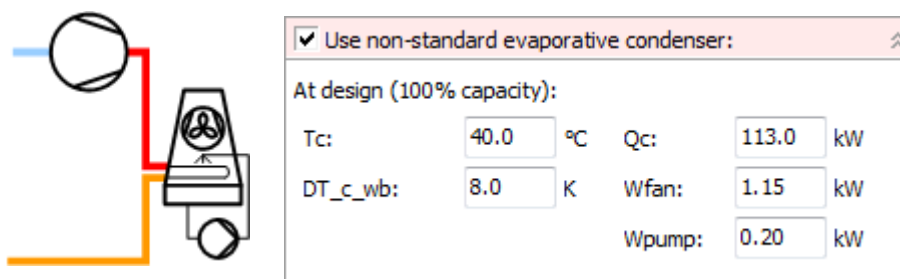
The settings for a dry cooler are the same as for an air-cooled condenser, except that the default values are different. Especially the default dimensioning temperature difference is larger, to accommodate the extra heat exchanger:

Dry cooler definition:

Condenser capacity at 0% fan capacity in percent of capacity at 100%:	<input type="text" value="4"/> %
Fan power at 100% in percent of condenser capacity at 100%:	<input type="text" value="3"/> %
Dimensioning temperature difference:	<input type="text" value="17.0"/> K

Note that the program doesn't directly consider the air and secondary fluid sides separately –the program regards the condenser as a “black box” with refrigerant on one side, air on the other, and some general relationships between power consumption and condenser capacity as described above. This also means that the DT for a dry cooler is the temperature difference between air in and refrigerant.

## B.3 Evaporative condenser



The settings for the evaporative condenser consists of a dimensioning condenser capacity (default value equals the condenser capacity of the selected compressors in the selected dimensioning state) and power consumption in a dimensioning state:

- **Tc.** Dimensioning condensation temperature. As default equal to the dimensioning condensation temperature for the selected compressors.
- **DT\_c\_wb.** Dimensioning temperature difference between condensation temperature and wet-bulb temperature.

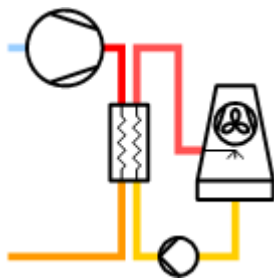
The default values can be changed in the Options | Preferences menu and are:

Evaporative condenser definition:	
Fan and pump power at 100% in percent of condenser capacity at 100%:	1.2 %
Dimensioning temperature difference, wet bulb to condensing:	8.0 K

Note that for an evaporative condenser it is assumed that the condenser capacity at 0% capacity equals 0 kW (i.e.,  $OA_0 = 0$  kW/K).

**Note:** For the current version, it seems that the automatic selection procedure for evaporative condensers tend to select a too small condenser.

## B.4 Cooling tower



Use non-standard cooling tower:			
At design (100% capacity):			
Tc:	40.0 °C	Qc:	113.0 kW
DT_c_wb:	15.0 K	Wfan:	1.44 kW
Liquid/gas ratio:	2.0 -	Wpump:	0.25 kW

The settings for the cooling tower consist of a dimensioning condenser capacity (default value equals the condenser capacity of the selected compressors in the selected dimensioning state) and power consumption in a dimensioning state:

- **Tc.** Dimensioning condensation temperature. As default equal to the dimensioning condensation temperature for the selected compressors.
- **DT\_c\_wb.** Dimensioning temperature difference between condensation temperature and wet-bulb temperature.
- **Liquid/gas ratio.** Ratio of water/air mass flow rates at dimensioning conditions

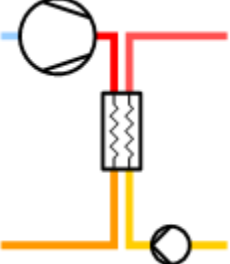
The default values can be changed in the Options | Preferences menu and are:

Cooling tower definition:	
Fan and pump power at 100% in percent of condenser capacity at 100%:	1.5 %
Dimensioning Liquid/gas ratio:	2 -
Dimensioning approach, condensing temperature - water in:	2.0 K
Dimensioning water temperature increase in condenser:	5.0 K
Dimensioning DT, condensing - wet bulb:	15.0 K
Dimensioning filling constant:	-0.62 -

The dimensioning approach and the dimensioning water temperature increase are used to calculate the mass flow of the water in the cooling tower. Merkel's equations for cooling tower are used to find the right L/G ratio, and resulting water/air flow, at the given condition.

## B.5 Water cooled

The model of the water-cooled condenser can be seen as a model for any other type of condenser, not fitting the rest of the condenser models.



**Water cooled**

Tw profile: Constant

Temperature for constant profile: 20.0 °C

Use non-standard water cooled condenser:

At design (100% capacity):

DT: 5.0 K      W\_pump: 3.39 kW

Qc: 113.0 kW

For the water-cooled condenser you define the condenser ambient temperature (water temperature) either as a profile or as a constant. The dimensioning DT is much smaller, thus UA value higher, than for other condensers.

The size of the condenser is as for the rest of the condenser models. The default values can be changed in the Options|Preferences menu and are:

Water cooled condenser definition:

Pump power at 100% in percent of condenser capacity at 100%:

3 %

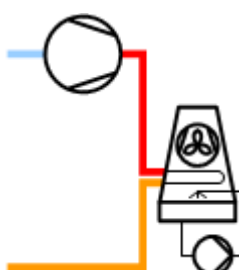
Dimensioning temperature difference:

5,0 K

## B.6 Hybrid cooler

Also known as adiabatic cooler.

This is essentially a combination of an air-cooled and evaporative condenser, which on hot days tries to saturate the air entering the condenser with water and on cold days runs purely air-cooled. The hybrid cooler model is experimental, and quite simple:



Use non-standard hybrid cooler:	
At 0 % capacity:	At 100 % capacity:
DT: 17.0 K	DT: 17.0 K
Qc: 4.5 kW	Qc: 113.0 kW
Efficiency: 0.75 -	Wfan: 2.88 kW
Tamb_min: 10.0 °C	Wpump: 0.51 kW
Vair: 24704 m <sup>3</sup> /h	

The hybrid cooler takes – besides capacity data – three parameters:

- Efficiency. A measure of how well the water system saturates the air. Calculated as:

$$Efficiency = \frac{T_{amb,dry} - T_{cond,amb}}{T_{amb,dry} - T_{amb,wet}} \Rightarrow$$

$$T_{cond,amb} = T_{amb,dry} - Efficiency \cdot (T_{amb,dry} - T_{amb,wet})$$

$T_{cond,amb}$  is the “ambient” temperature used when calculating the condenser. So when the efficiency is 0, then  $T_{cond,amb}$  is equal to the dry temperature (air cooled condenser) and when the efficiency is 1,  $T_{cond,amb}$  is equal to the wet bulb temperature (evaporative condenser).

- Tamb\_min: The minimum (dry) ambient temperature where water is used on the cooler. I.e., the hybrid cooler works as an air-cooled condenser when it is colder, and as an evaporative condenser when it's warmer.
- Vair: Air volume flow, used to calculate water consumption.

The default values can be changed in the Options | Preferences menu and are:

Hybrid cooler definition:	
Condenser capacity at 0% fan capacity in percent of capacity at 100%:	4 %
Fan power at 100% in percent of condenser capacity at 100%:	3 %
Dimensioning temperature difference:	17,0 K
Default humidifying pad efficiency:	0,75 -
Default minimum dry-bulb temperature, above which water system is enabled:	10,0 °C

## C System descriptions

For each system model, a description will be made available in this Appendix. The modelling approach will be explained, as well as any assumptions and simplifications done in the model.

### C.1 One stage

#### C.1.1 One stage transcritical

#### C.1.2 One stage transcritical, parallel compression

#### C.1.3 One stage transcritical, ejector (v5.2, March 2022)

The one-stage transcritical ejector cycle has two different operation modes: **Ejector mode** and **gas bypass mode**, see Figure 1. In **ejector mode**, the gas bypass valve is fully open, and the check valve is closed (grey color). In case the ejector cannot provide a pressure lift ( $\Delta P_{\text{lift}}$ ) larger than the minimum pressure lift ( $\Delta P_{\text{min}}$ ), the gas bypass valve begins to close and controls the pressure difference between the flash gas receiver and the suction line at the minimum pressure lift, thus the check valve open and **gas bypass mode** begins. This procedure ensures a minimum pressure drop across the expansion valve for superheat control in real systems. The minimum pressure lift setpoint can be defined in the "additional preferences" of the "suction side" tab.

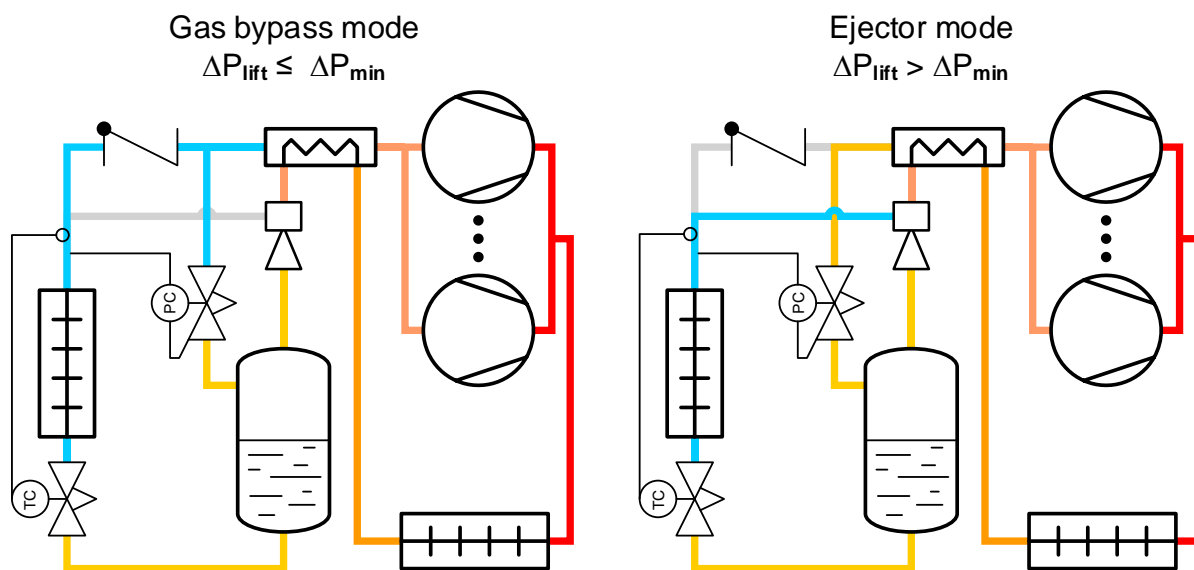


Figure 1: One-stage transcritical ejector cycle. Ejector mode (right) and gas bypass mode (left).

The ejector efficiency is so far calculated by a dimensionless efficiency map in reference:

Haider, M., & Elbel, S. (2021). Development of ejector performance map for predicting fixed-geometry two-phase ejector performance for wide range of operating conditions. *International Journal of Refrigeration*, 128, 232-241. <https://doi.org/10.1016/j.ijrefrig.2021.03.022>

The paper includes a new definition of the ejector efficiency as opposed to the older (2008) by the same Authors. Both efficiencies can be observed in the "yearly" plots tab as well as the entrainment ratio and pressure lift. The efficiency map does not rely on performance data from ejector

manufacturers, thus the ejector cycle is so far experimental. The goal is to include ejectors from manufacturers in future releases.

#### C.1.4 One stage transcritical, ejector, parallel compression (v5.3, November 2022)

The one-stage transcritical ejector cycle with parallel compression integrates both advantages from using ejectors and parallel compressors. The parallel compressors consume as much as possible of the flash-gas production through the ejector and the vapor suction from the evaporator. Any remaining gas is bypassed to the suction of the main compressors. When the gas production is high at very high ambient temperatures, a check valve ensures the bypassed gas is not recirculated through the ejector suction. The ejector consumes as much gas as possible from the evaporator and is dependent on the specified intermediate temperature in the receiver.

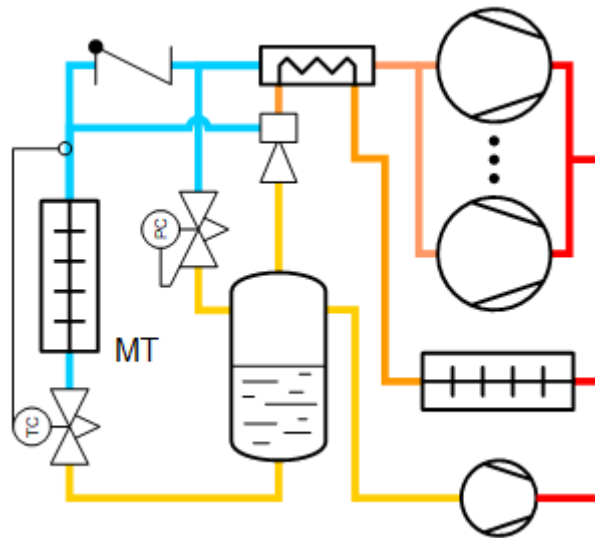


Figure 2: One-stage transcritical ejector with parallel compression

The ejector efficiency is calculated like C.1.3 One stage transcritical, ejector (v5.2, March 2022). This ejector map is not developed for parallel compression, nor does it rely on manufacturers data, thus the ejector cycle is so far experimental. The goal is to include ejectors from manufacturers in future releases.

## C.2 Two one stage

### C.2.1 Two one stage, common condenser

## C.3 Cascade

### C.3.1 Cascade, transcritical

### C.3.2 Cascade, CO2

## C.4 Two stage

### C.4.1 Two stage transcritical

### C.4.2 Two stage transcritical, parallel compression

### C.4.3 Two stage transcritical, ejector (v5.3, November 2022)

The working principle of the two-stage transcritical ejector cycle is similar to the C.1.3 One stage transcritical, ejector (v5.2, March 2022), but including the low temperature stage. The gas produced from the low temperature (LT) compressors is connected to the suction of the medium temperature (MT) compressors. The ejector consumes the full mass flow through the medium temperature evaporator. In case the pressure lift provided by the ejector is smaller than the specified minimum, the cycle is operated as the standard gas bypass mode.

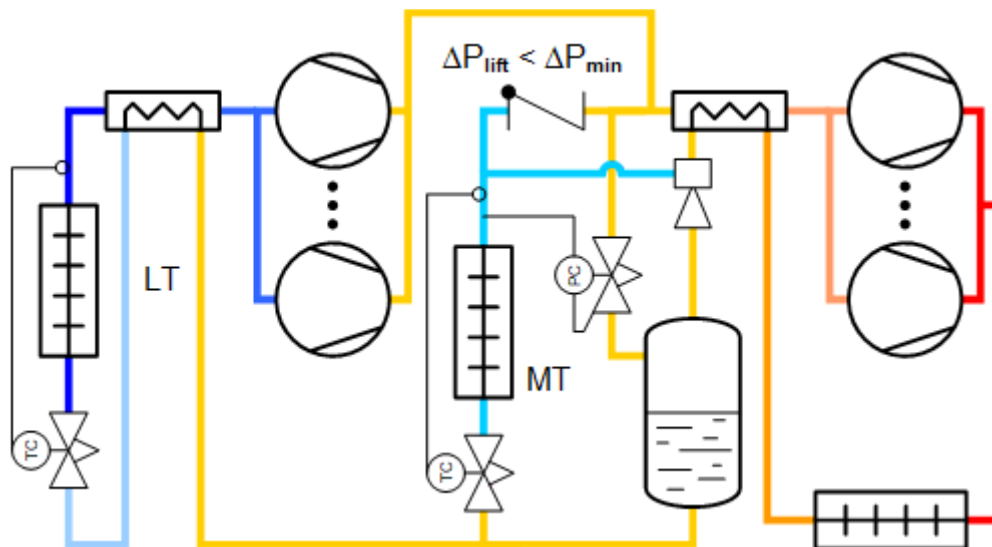


Figure 3: Two-stage transcritical ejector cycle

The ejector cycle is so far experimental. The goal is to include ejectors from manufacturers in future releases.

#### C.4.4 Two stage transcritical, ejector, parallel compression (v5.3, November 2022)

The working principle of the two-stage transcritical ejector cycle with parallel compression is similar to the C.1.4 One stage transcritical, ejector, parallel compression (v5.3, November 2022), but including the low temperature stage. The ejector consumes as much as possible through the medium temperature evaporator. In some cases, the gas produced from the low temperature compressors may also be consumed by the ejector suction depending on the LT/MT load ratio.

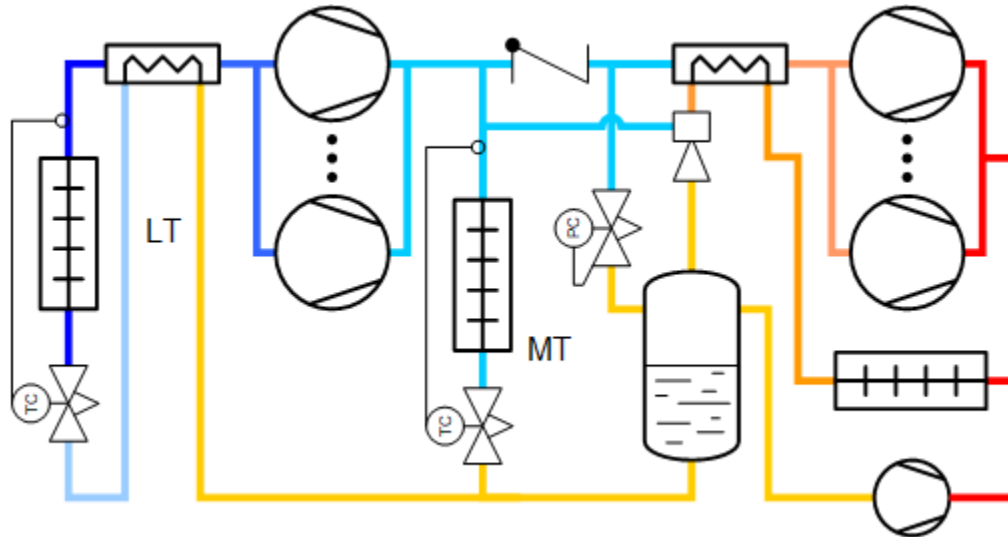


Figure 4: Two-stage transcritical ejector cycle with parallel compression

The ejector cycle is so far experimental. The goal is to include ejectors from manufacturers in future releases.

#### C.4.5 Two stage open intercooler

#### C.4.6 Two stage closed intercooler

#### C.4.7 Two stage liquid injection

### C.5 Heat pump

#### C.5.1 Cascade heat pump, subcritical (v5.2, March 2022)

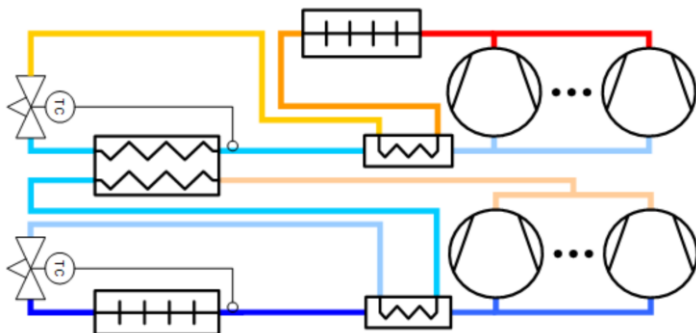


Figure 5: Cascade heat pump PI diagram



The cascade heat pump model moves heat from the LT evaporator to the MT condenser.

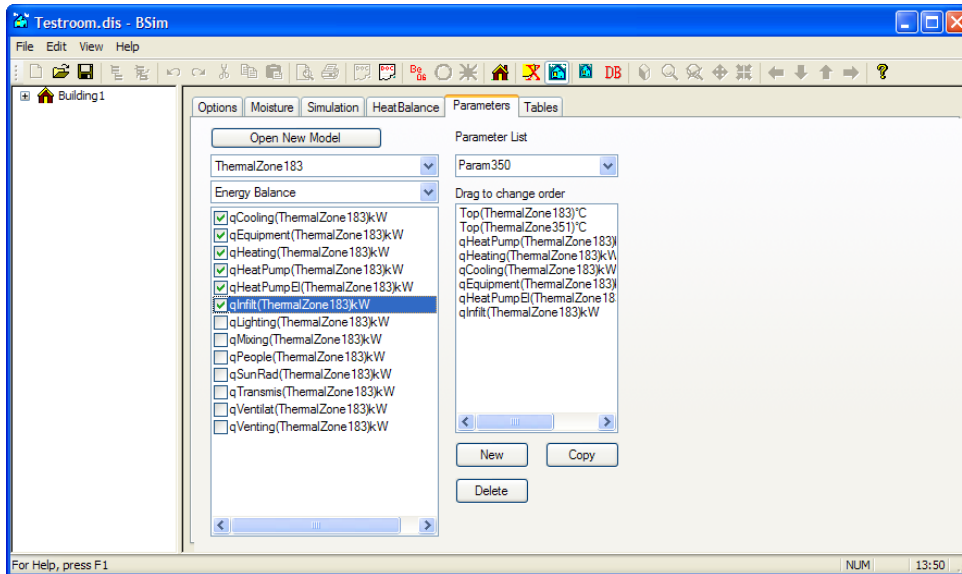
The intermediate pressure can be assumed to be a fixed value or controlled such that the pressure ratios of the LT and MT packs are approximately equal, even for different refrigerants. A maximum evaporation temperature for the MT pack (so indirectly also maximum condensing temperature for LT pack) can be set too.

The cascade heat exchanger is dimensioned by using a standard temperature difference of 5 Kelvin (can be changed in preferences). The actual temperature difference between LT and MT pack is optimized based on the dimensioned size, so if the cascade heat exchanger is over-dimensioned for some operating condition, the temperature difference between the two sides is decreased accordingly. This is done by decreasing the LT discharge pressure, rather than increasing MT suction pressure, to optimize the calculation speed.

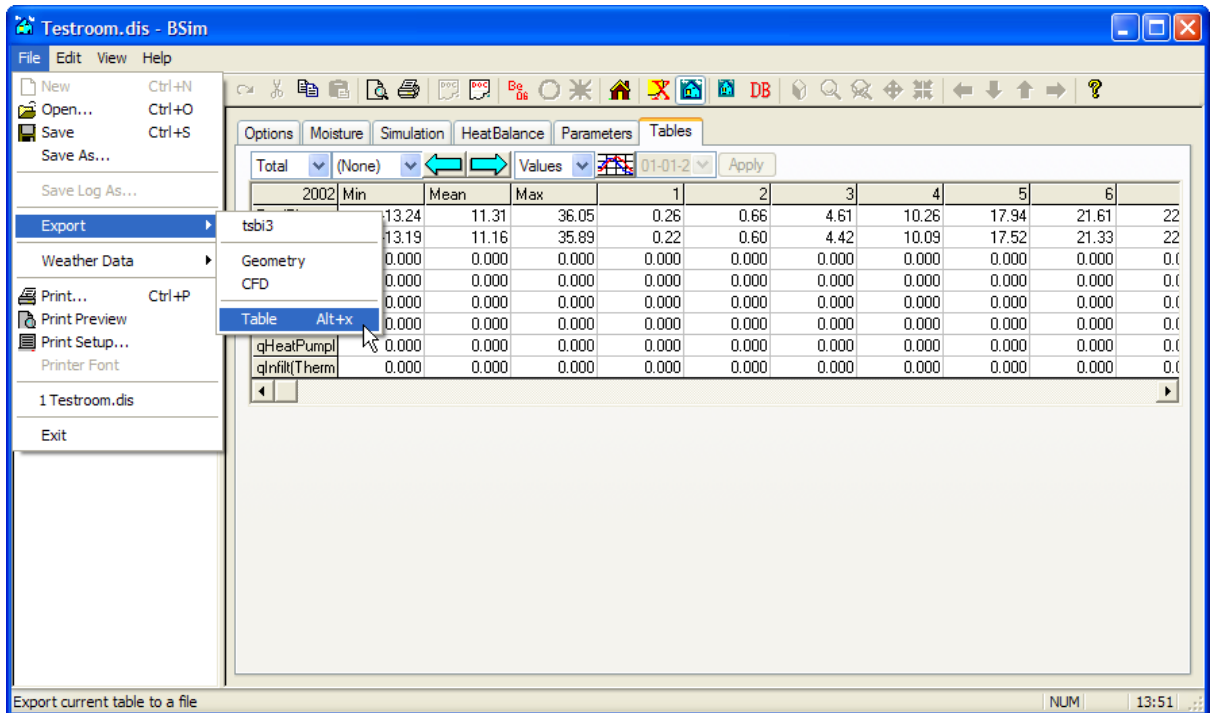
## D Integration with BSim

In BSim you export the data by:

- 1) Add relevant parameters to your simulation results:

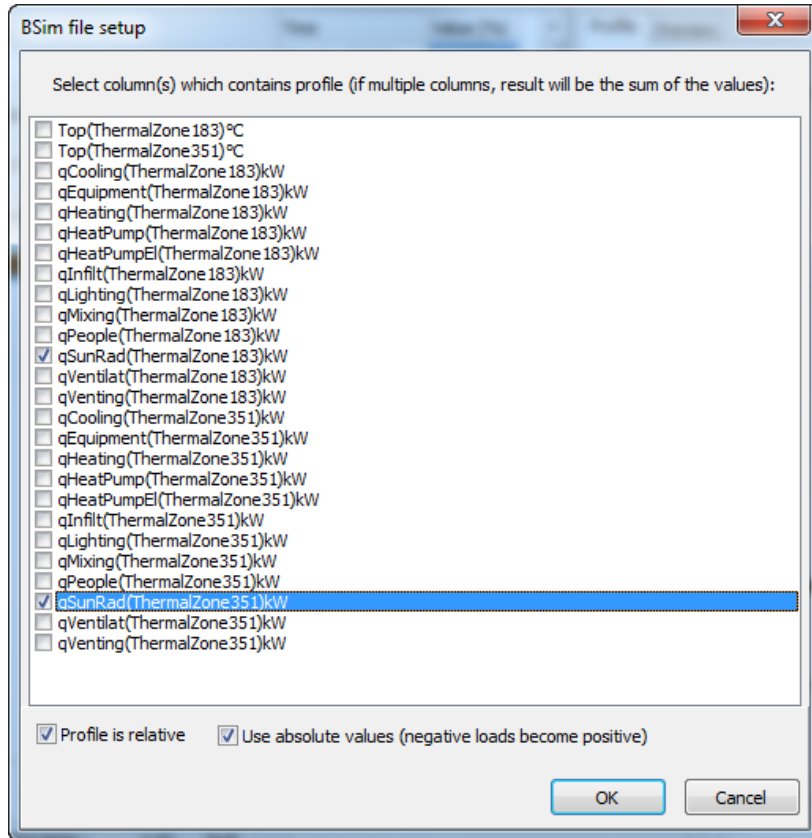


- 2) Run the simulation for one year
- 3) Go to the Tables tab, and export the table:

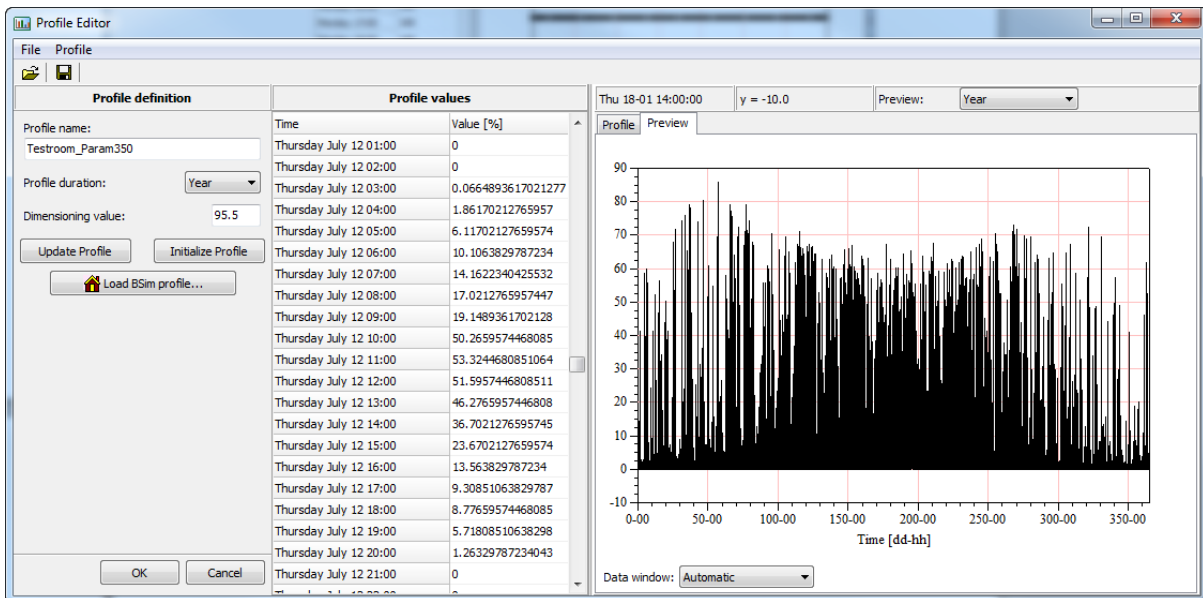


The file you generate can be loaded directly into PackCalc.

When you open the file from the Profile editor (see chapter 7.1.1), you'll see the following dialog:



Here you select the values you want to include in the load profile. If you select multiple values the sum of the values is used:



## E Rules of thumb for raising temperatures

When you run simulations with constant evaporation temperature (see also 7.1.5), then it can be very difficult proving energy savings using variable speed compressors and fans. Experience shows though, that if you have variable speed control then operation is much smoother. Depending on whether you use electronic or thermostatic expansion valves, you can raise the evaporation temperature and go lower in condensation temperature if you use variable speed control. The following rules of thumb can be used to provide a guideline.

### Variable speed compressors

1. If you use variable speed compressors and you use electronic expansion valves, you can raise the evaporation temperature 2 K. If you for example are comparing a system with fixed speed compressors having an evaporation temperature of -12 °C, with a system with variable speed compressors, then you should set the evaporation temperature of the variable speed system to -10 °C.

### Variable speed fans (or pumps)

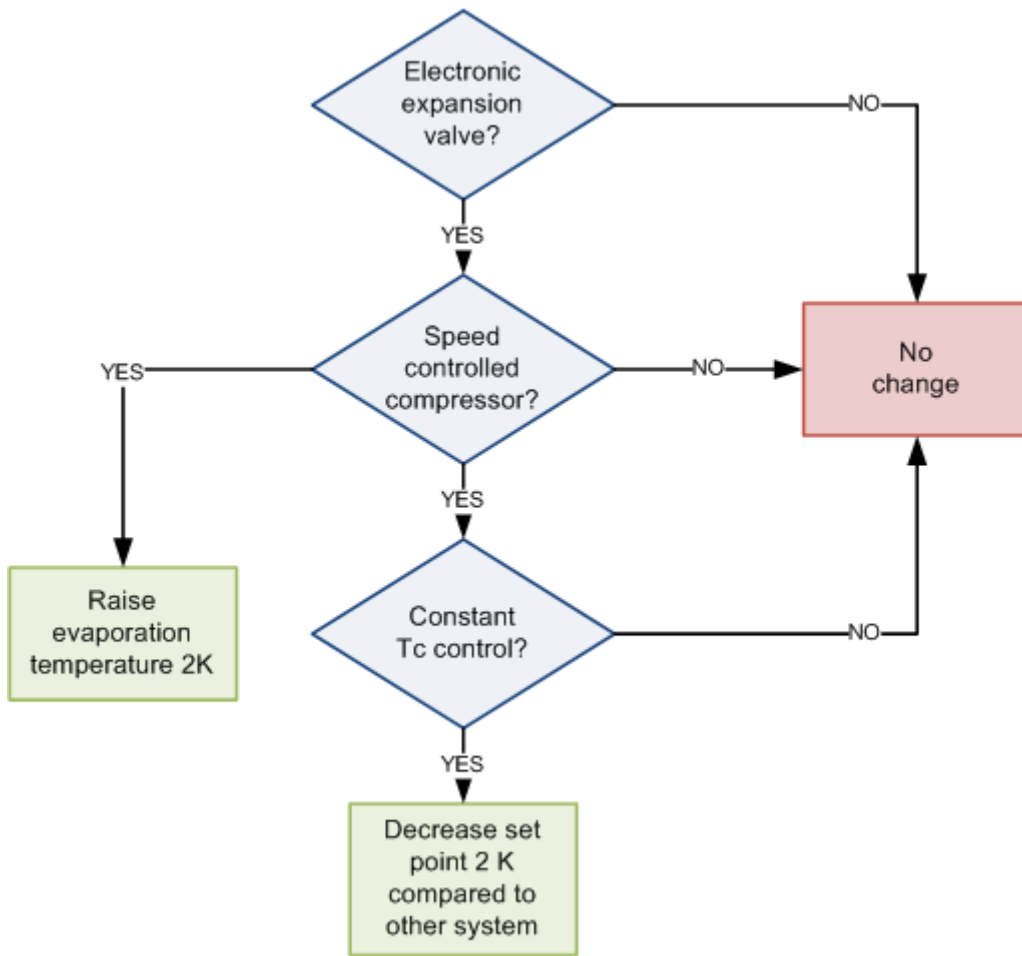
If you control the condenser capacity so that the condensation temperature to follow the ambient temperature, then you should change the *minimum condensation temperature* according to whether you use variable speed fans, but also according to your expansion valve type:

1. Electronic expansion valve
  - a. If speed control on condenser fans, then the minimum condensation temperature can be set to 20 °C
  - b. If not speed control on condenser fans, then the minimum condensation temperature should be set to 25 °C
  - c. If you use CO<sub>2</sub>, then the minimum condensation temperature can be set to 10 °C
2. Thermostatic expansion valve (or other non-electronic valves)
  - a. If speed control on condenser fans then the minimum condensation temperature can be set to 25 °C
  - b. If not speed control on condenser fans then the minimum condensation temperature should be set to 28 °C

If you control the condenser capacity according to a constant condensation temperature, then the set point can be 2 K lower for a system with speed-controlled fans compared to a system with fixed speed fans.

The rules are illustrated below:

### Compressors



### Fans (and pumps)

