

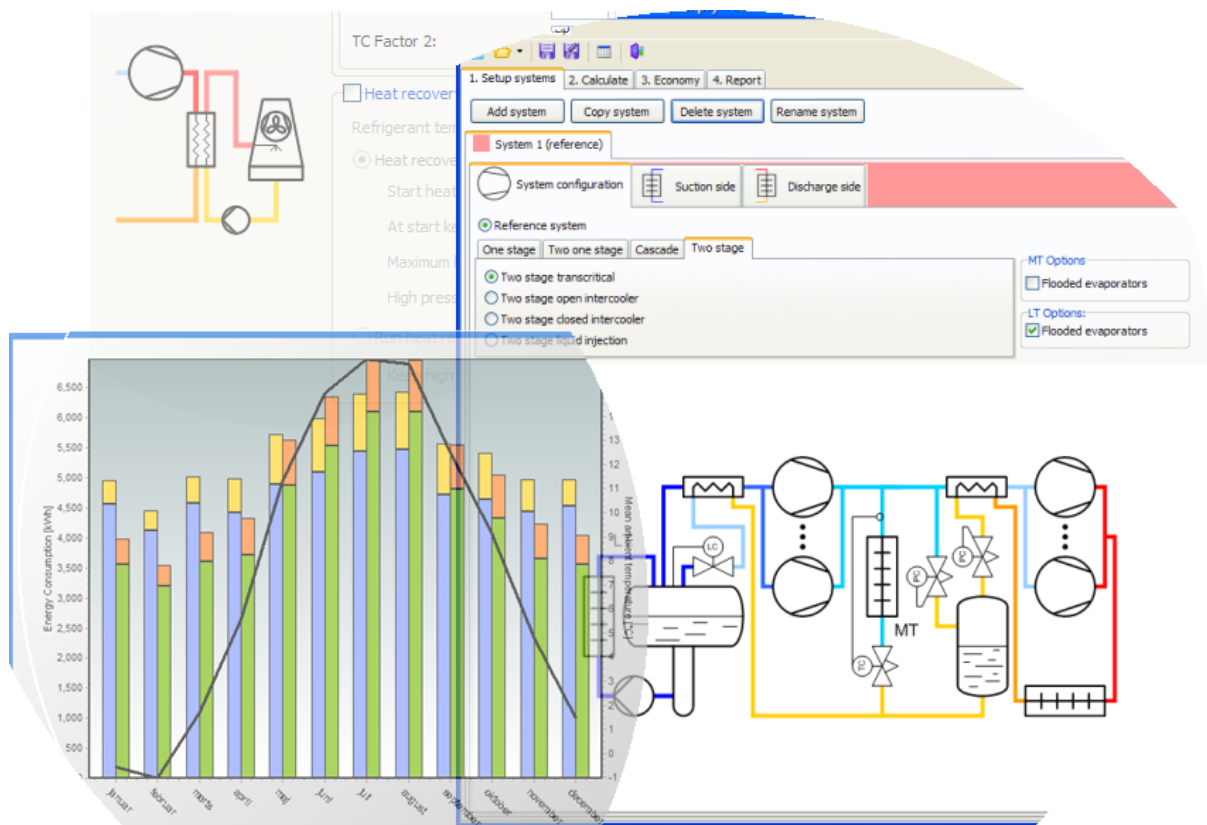
Pack Calculation Pro



Users guide

Version 4.10

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2 Introduction

Pack Calculation is an application for comparing the yearly energy consumption of refrigeration systems and heat pumps. Among other features, transcritical CO₂ systems can be compared with traditional systems. The application compares different systems based on a geographical location.

Traditionally, refrigeration systems (and heat pumps) are dimensioned based on a single operating point (normally somewhere around the point where the load is highest). This approach ensures that the system will deliver the cooling (or heating) required, but it 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 benefit from a lower optimal pressure ratio for example...)
- It is difficult to evaluate payback time of energy saving measures based on a full load operating condition... Often energy saving measures only shows their value at part load conditions.

These drawbacks are all addressed in Pack Calculation Pro:

- The performance of the defined systems is evaluated every hour of the year (= 8760 operating points)
- You can get a clear overview of how well you system actually meet the demands (load profile) that you define – but also get an overview of the part load performance
- You can select weather data from more than 700 locations from all around the world
- You can compare systems under the exact same load and ambient conditions, evaluating the effect of energy saving measures
- You can compare the energy consumption of the systems, but you can also make economic calculations - Payback time and Life Cycle Costs – and compare CO₂ emissions for the different systems.
- Pack Calculation Pro contains models (based on manufacturer data) of more than 7000 commercially available compressors, which ensures that you are able to model most systems, and equally important, you get results for off-design operation which is not based on theoretical assumptions.

Recently, standards for measuring seasonal performance of both refrigeration systems and heat pumps, have appeared. Pack Calculation Pro provides a more detailed simulation of the yearly energy consumption than the standards offer. This is because the standards are based on a few measurements at different loads and some generalized climate conditions – it is practically impossible to measure a real system in several different locations for different loads for a whole year... Pack Calculation Pro on the other hand enables you to do exactly this.

Moreover you are able to create reports documenting the results of your calculations.

The different elements of Pack Calculation Pro will be explained in detail in the following chapters, but first an example is given.

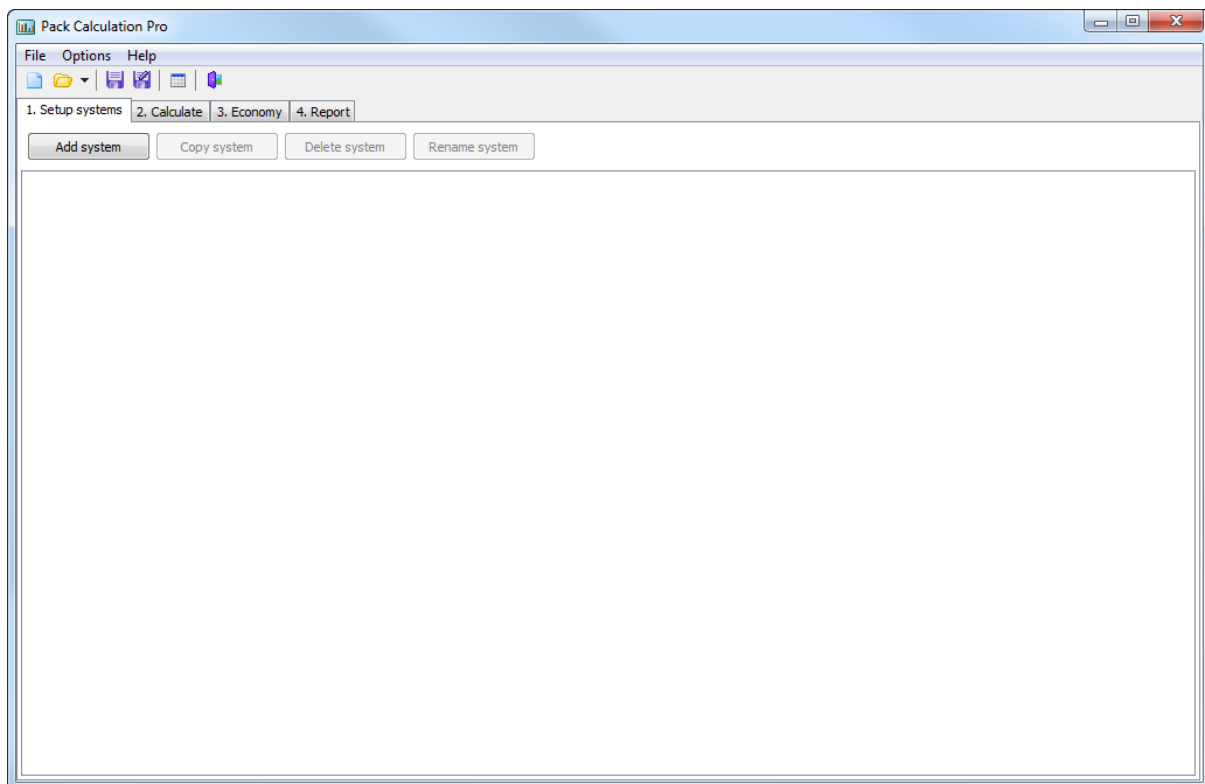
3 Example

The procedure for comparing systems in Pack Calculation Pro (hereafter PackCalc) involves the following steps:

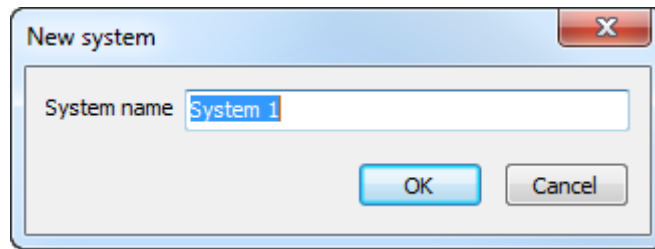
1. Setup systems – which simply involves selecting one of the 11 different refrigeration systems (including transcritical CO₂ systems) or the heat pump system. For each system, you define you need to:
 - a. Select compressors – either by defining generic compressors or selecting from a database
 - b. Define the suction side of the system (load profile, evaporation temperature, etc.)
 - c. Define the discharge side of the system (condenser type, control,...)
 - d. Add groundwater cooling if applicable
2. Calculate energy consumption
3. Calculate payback time, life cycle costs and CO₂ emissions
4. Create a report documenting your findings

3.1 Setup systems

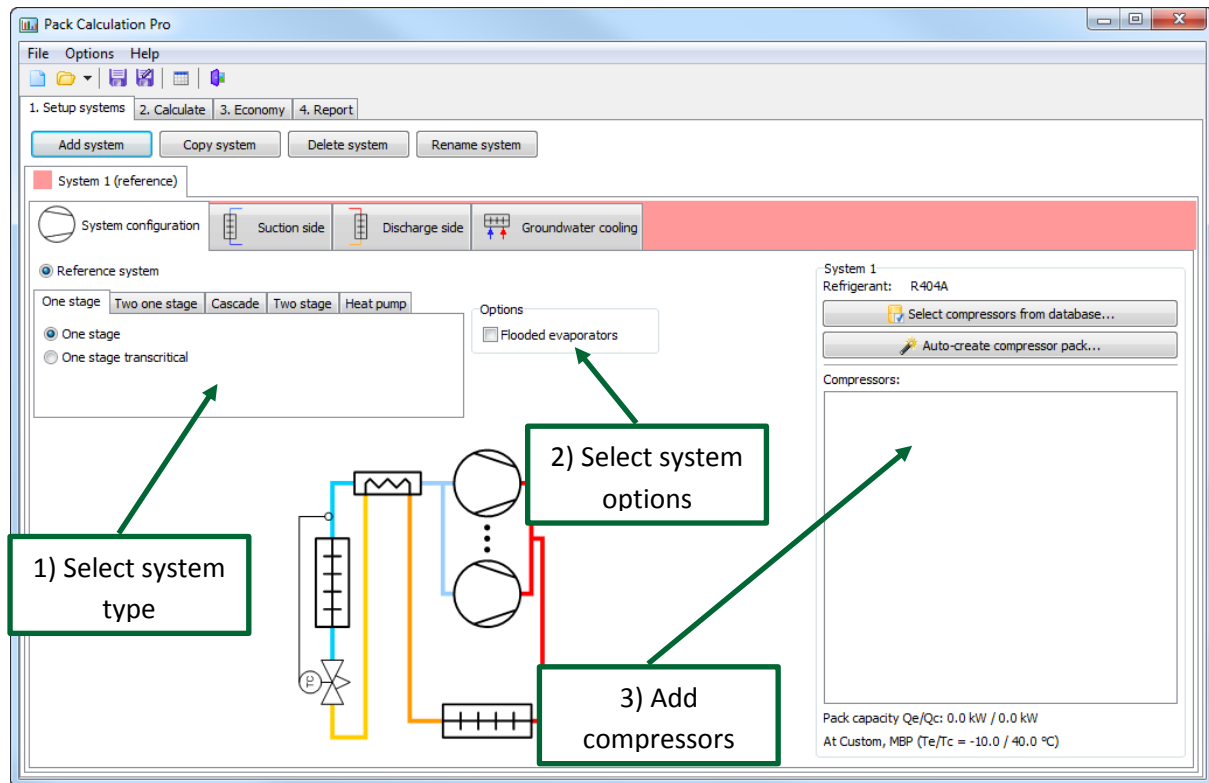
At startup PackCalc looks like the following screen dump:



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:

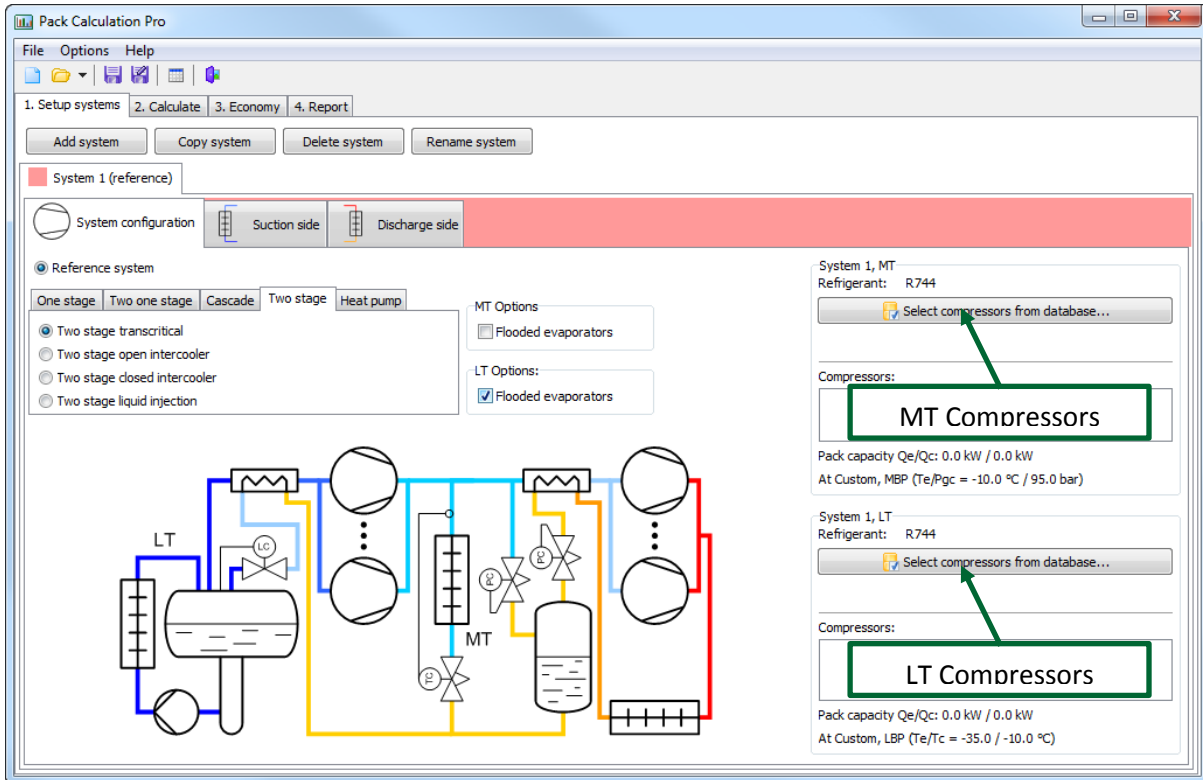


The first system you add will automatically be selected as the “Reference system”, i.e. the system any other systems will be compared to.

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

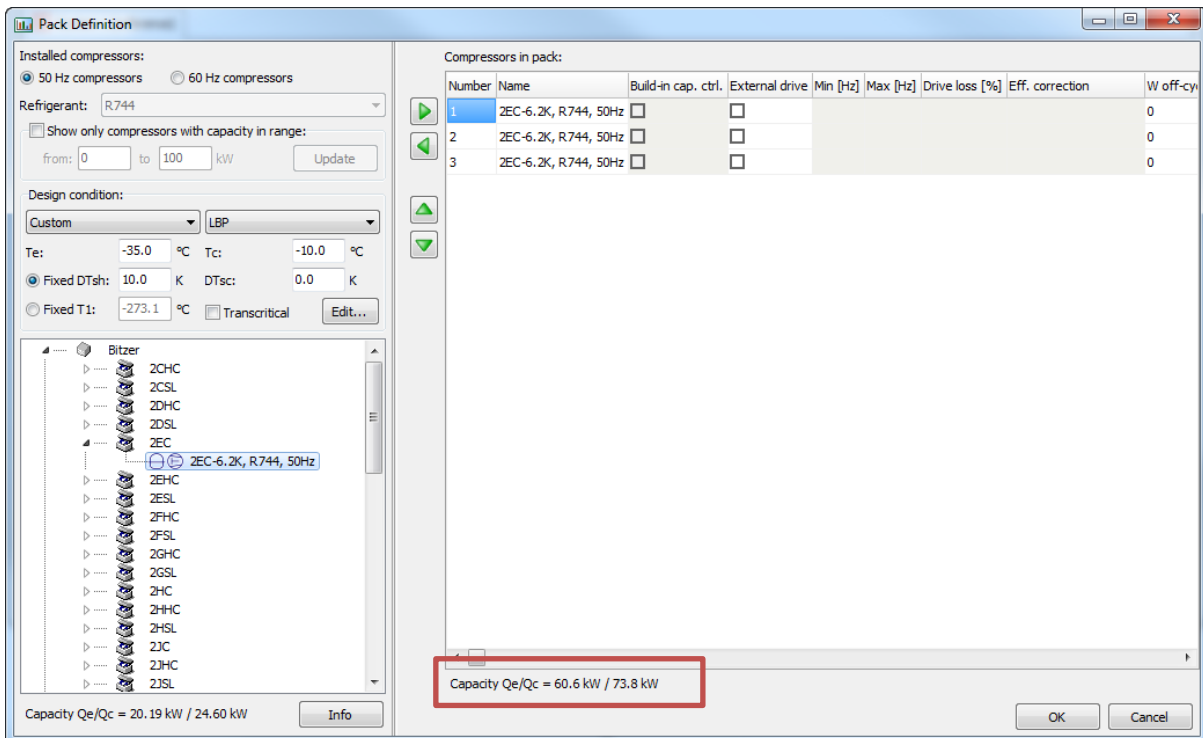
1. Select the wanted system type
2. Select options - typically whether the evaporators are flooded or dry expansion (default)
3. Add compressor to the system you’ve chosen

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



3.1.1 Selecting compressors

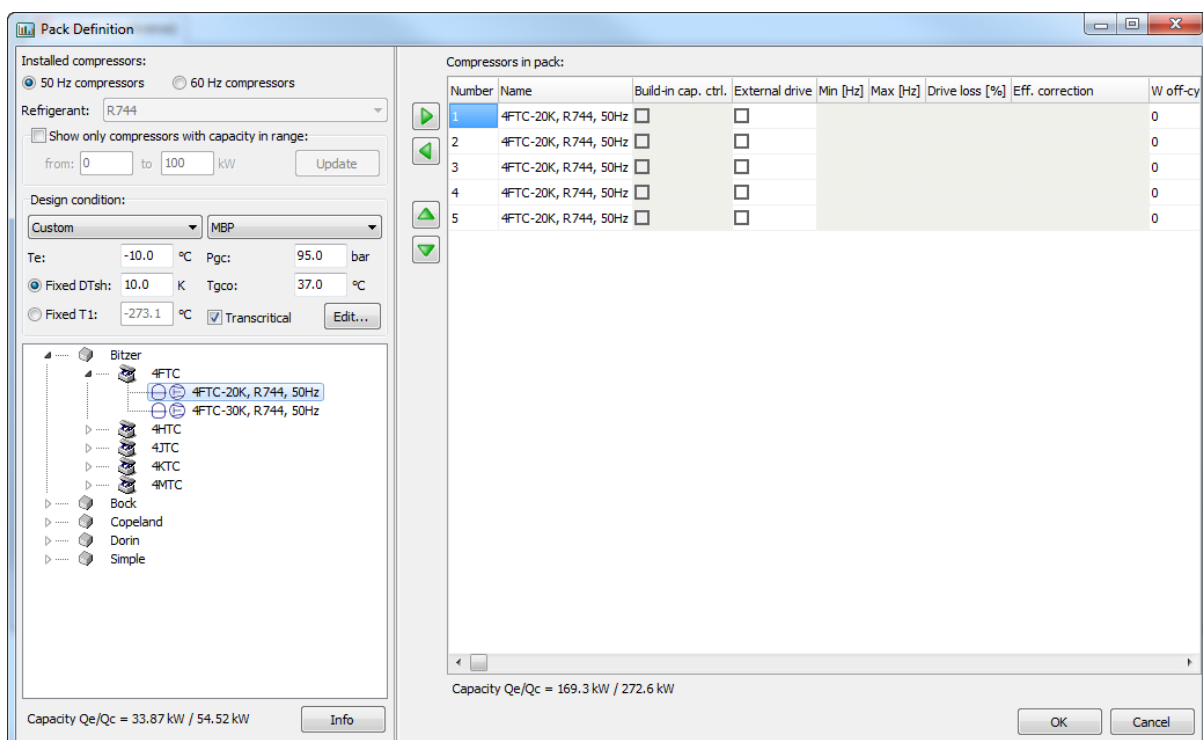
The next thing to do is to add compressors to the system. In this example we need to define compressors for both the low temperature (LT) and the medium temperature (MT) stage. First we define the LT compressors, which has to be CO₂ compressors (remember we selected a two stage transcritical system and this implies CO₂ 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 60.6 kW and a condenser capacity of 73.8 kW. These numbers are important as they are used later!

The parameters/options you can define for each compressor are explained in chapter 5, 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 $T_e = -10\text{ °C}$ 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 °C, and then the capacity of the compressors will be lower than 100 kW).

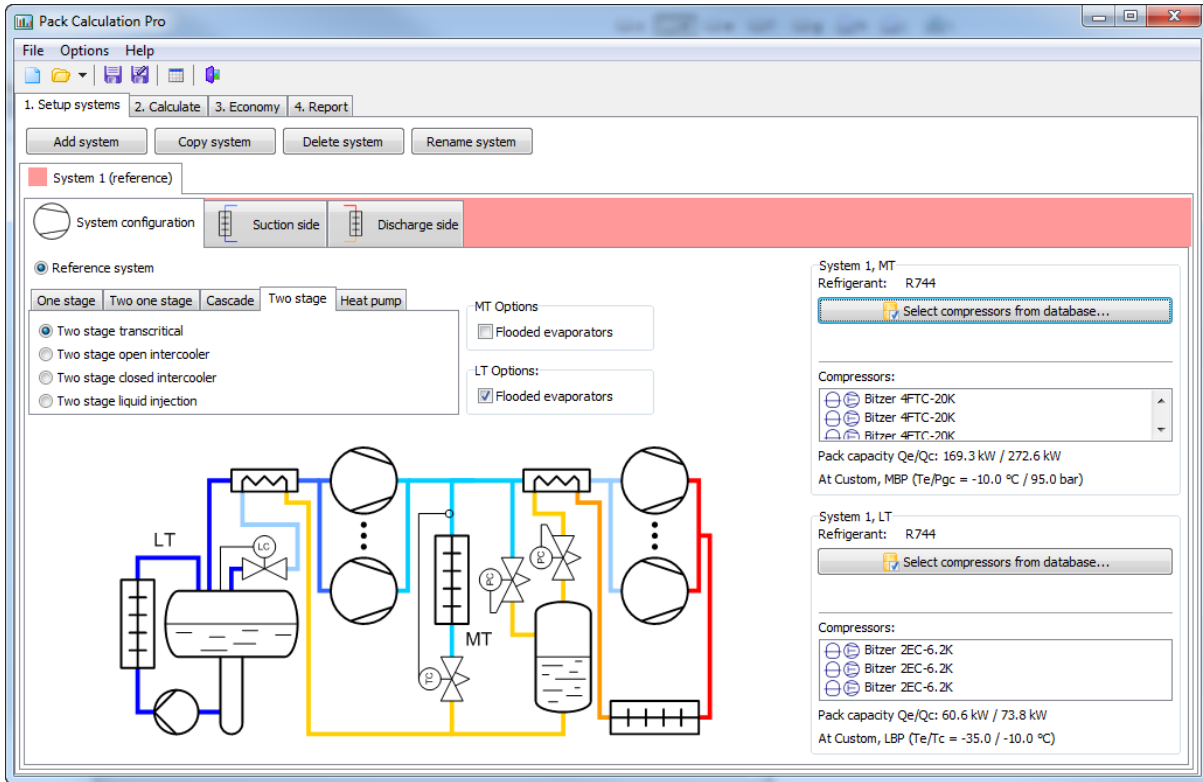
When done press [OK] and you're back to the main screen. Then you select the MT compressors:



Note that here you are also limited (besides having CO₂ as refrigerant) to transcritical compressors. Note also that as the LT compressors had a dimensioning condenser capacity of 73.8 kW the MT compressors only have 169.3 kW – 73.8 kW = 95.5 kW left for actual doing 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:



Again, note the capacity of the two compressor packs:

LT (Low Temperature) pack:

- Cooling capacity $Q_e = 60.6 \text{ kW}$
- Condenser/heating capacity $Q_c = 73.8 \text{ kW}$

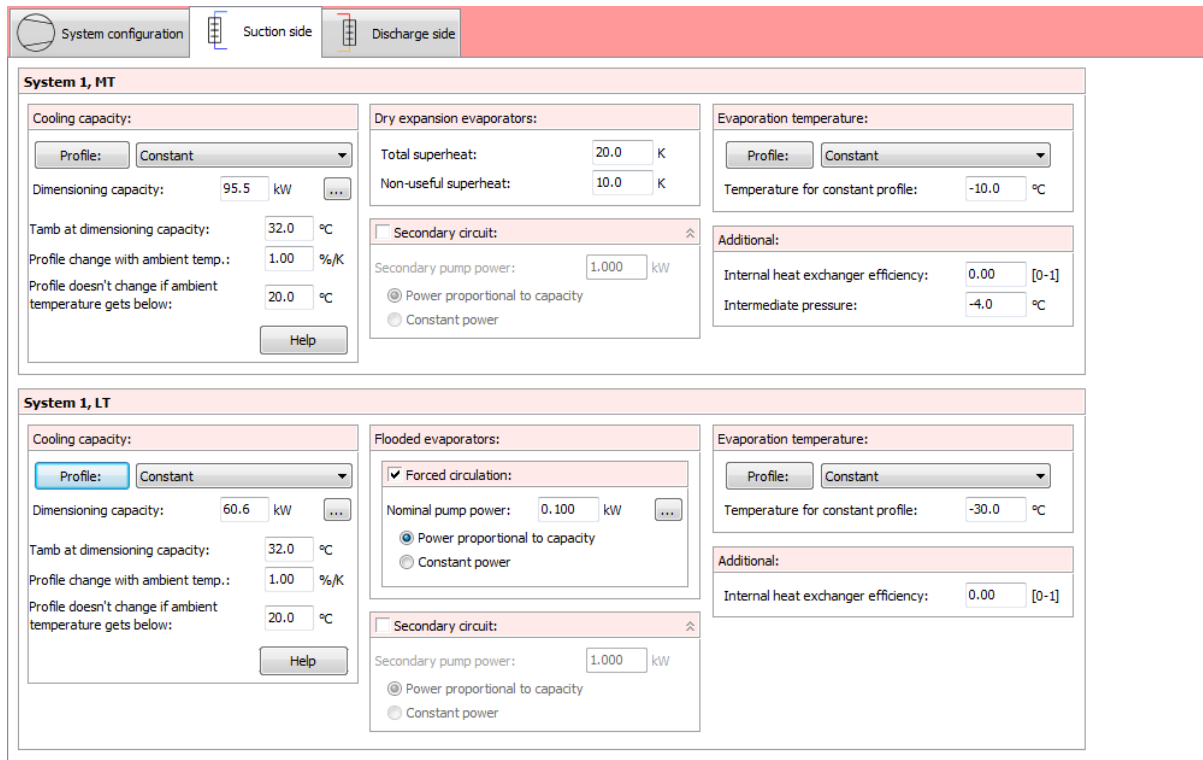
MT (Medium Temperature) pack:

- Cooling capacity, total $Q_e = 169.3 \text{ kW}$
- Cooling capacity for MT evaporators $Q_e, \text{ evap} = 169.3 \text{ kW} - 73.8 \text{ kW} = 95.5 \text{ kW}$
- Condenser/heating capacity $Q_c = 272.6 \text{ kW}$

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

3.1.2 Suction side

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



The screenshot displays the configuration for two systems: System 1, MT and System 1, LT. The interface is divided into three main sections: System configuration, Suction side, and Discharge side. The MT configuration includes fields for cooling capacity (95.5 kW), profile (Constant), ambient temperature (32.0 °C), and various superheat parameters. The LT configuration includes fields for cooling capacity (60.6 kW), profile (Constant), ambient temperature (32.0 °C), and forced circulation options.

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 6.1.1).
- **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 evaporator you have selected, you should then 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 lower the evaporation temperature a few degrees.

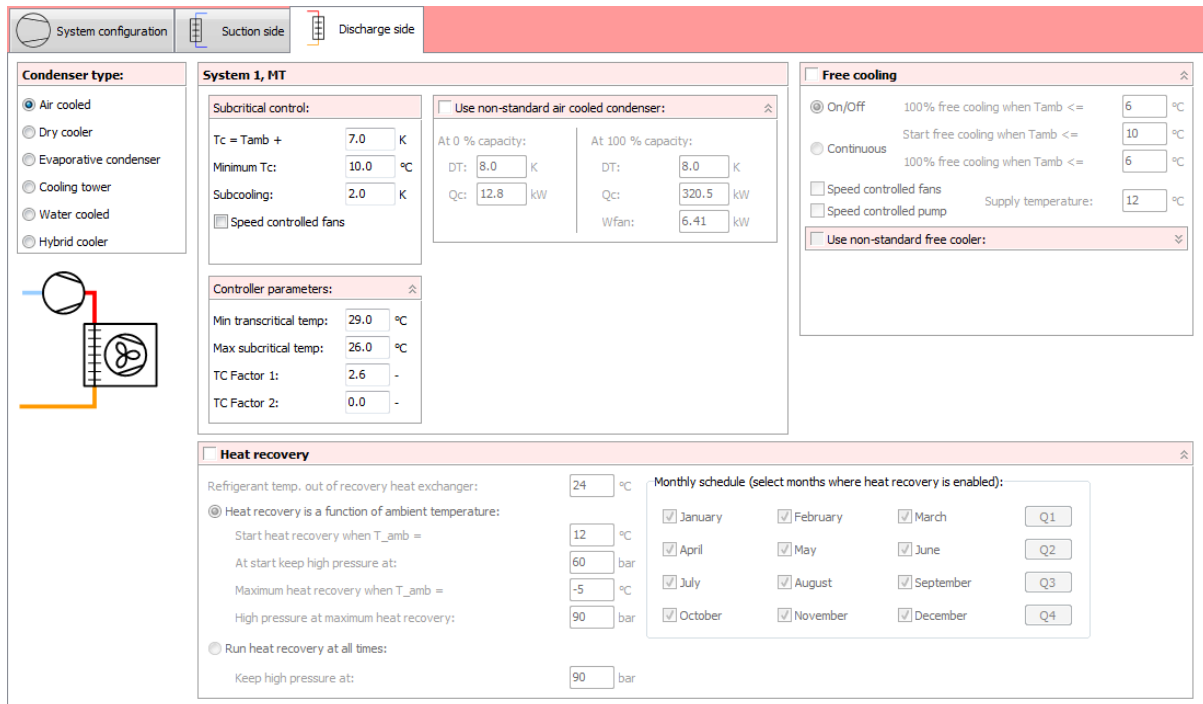
Depending on the system you have selected, you should specify the following additional values:

- **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).
- **CO₂ pump power.** Only applicable for cascade CO₂ systems. Enables you to define power consumption of the CO₂ pump.
- **Intermediate pressure.** Only applicable for two stage systems. For “standard” two-stage systems it is the pressure in the intercooler, for CO₂ systems it is the pressure in the separator.
- **Cascade temperature diff.** Temperature difference across cascade heat exchanger in cascade systems.
- **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 you can change by selecting the Options|Preferences menu (see chapter 8).

3.1.3 Discharge side

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



Condenser type:

- Air cooled
- Dry cooler
- Evaporative condenser
- Cooling tower
- Water cooled
- Hybrid cooler

System 1, MT

Subcritical control:

Tc = Tamb + K

Minimum Tc: °C

Subcooling: K

Speed controlled fans

Use non-standard air cooled condenser:

At 0 % capacity:		At 100 % capacity:	
DT:	<input type="text" value="8.0"/> K	DT:	<input type="text" value="8.0"/> K
Qc:	<input type="text" value="12.8"/> kW	Qc:	<input type="text" value="320.5"/> kW
		Wfan:	<input type="text" value="6.41"/> kW

Controller parameters:

Min transcritical temp: °C

Max subcritical temp: °C

TC Factor 1: -

TC Factor 2: -

Free cooling

On/Off 100% free cooling when Tamb <= °C

Start free cooling when Tamb <= °C

Continuous 100% free cooling when Tamb <= °C

Speed controlled fans Supply temperature: °C

Speed controlled pump

Use non-standard free cooler:

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: bar

Maximum heat recovery when T_amb = °C

High pressure at maximum heat recovery: bar

Run heat recovery at all times:

Keep high pressure at: bar

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"/>

You first have to 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.

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 for example 15 °C, the program will try to find the capacity (0 to 100%) of the fans that gives 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 try to rise the condensation temperature until the fan capacity is 100%.

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

Transcritical condenser control parameters

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.

Furthermore you can specify the following controller parameters, which corresponds to the high pressure control settings you can set in a Danfoss EKC 326A controller (see the documentation on www.danfoss.com for details):

- **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**. Decides together with **TC Factor 2** how the controller behaves in transition mode.

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	

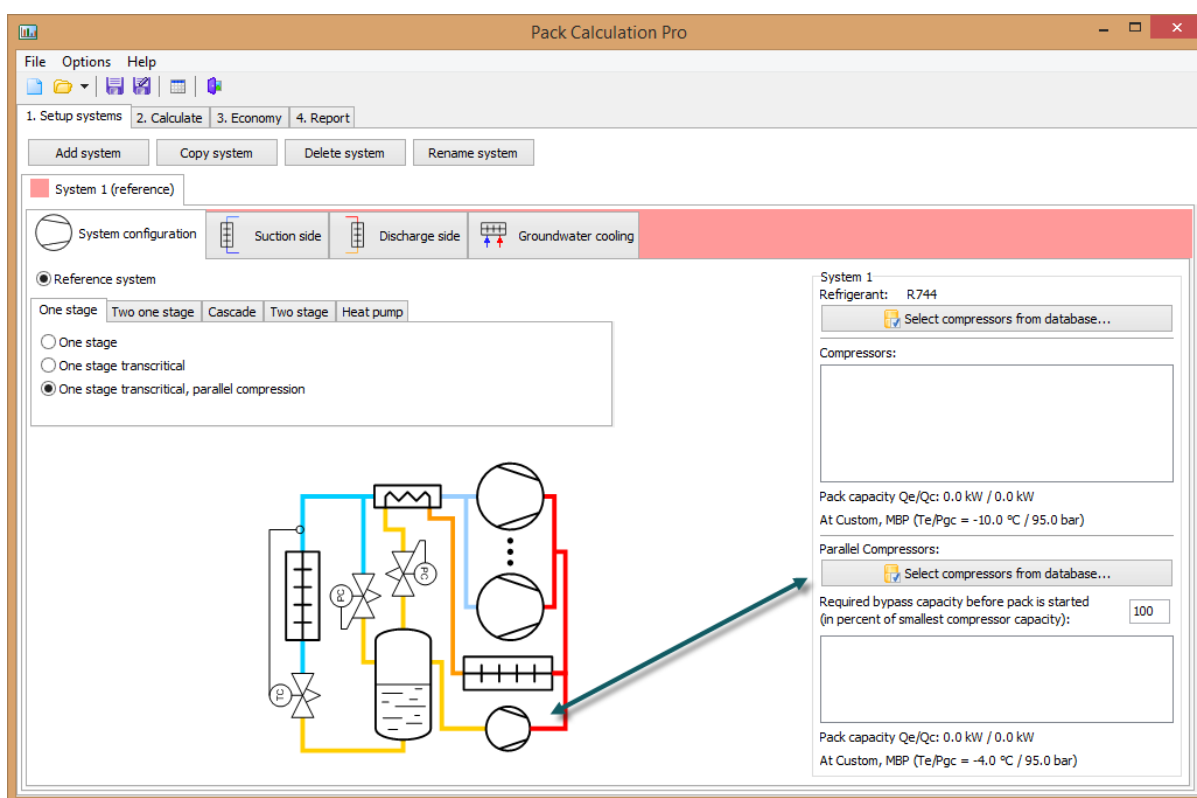
If the system is not transcritical, you can select two other condenser capacity control methods (besides $T_c = T_{amb} + b$):

- **Constant T_c .** 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.

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.

3.2 Parallel Compression

As of version 4.10 you can select transcritical one- and two-stage systems where the gas bypass (in defined periods) is done by one or more parallel compressors (instead of using the bypass valve):

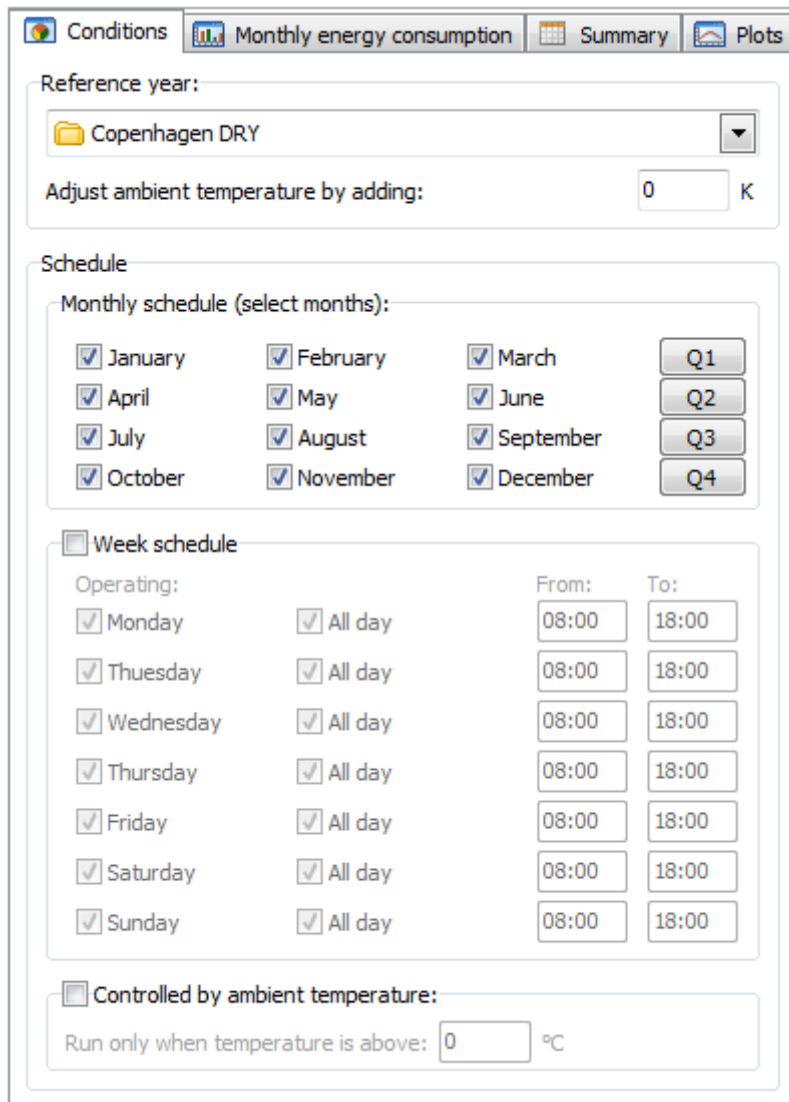


Adding parallel compressors works just like adding normal compressors. The only extra parameter is the “Required bypass capacity...” value – let’s call it X in the following. In every hour the mass flow in the bypass, \dot{m}_{bp} , is calculated. If the smallest capacity of the smallest compressor – among the parallel compressors – is larger than $X \cdot \dot{m}_{bp}$ then the bypass flow is handled by the parallel compressors, else it is handled by the bypass valve. This means that 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). Using parallel compressors in transcritical systems will contribute to energy savings – especially in hot climates.

The calculation can only handle either bypass valve or parallel compressor. This means that if the capacity of the parallel compressor is too small in a given situation, then a warning will be issued and the calculation will continue using a calculated over-capacity of the parallel compressor – i.e. the calculation will automatically increase the capacity over the parallel pack (included the extra power consumption that follows). In practical systems, any capacity that isn't handled by the parallel compressor will be passed through the bypass valve... This scenario is currently not supported by Pack Calculation Pro (due to calculation speed).

3.3 Calculation

At this point you are basically ready to calculate the system. First you should select the wanted geographical location though and possibly a schedule for the system:



The screenshot shows the software interface with the following configuration options:

- Conditions** (selected tab):
 - Reference year: Copenhagen DRY (dropdown menu)
 - 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

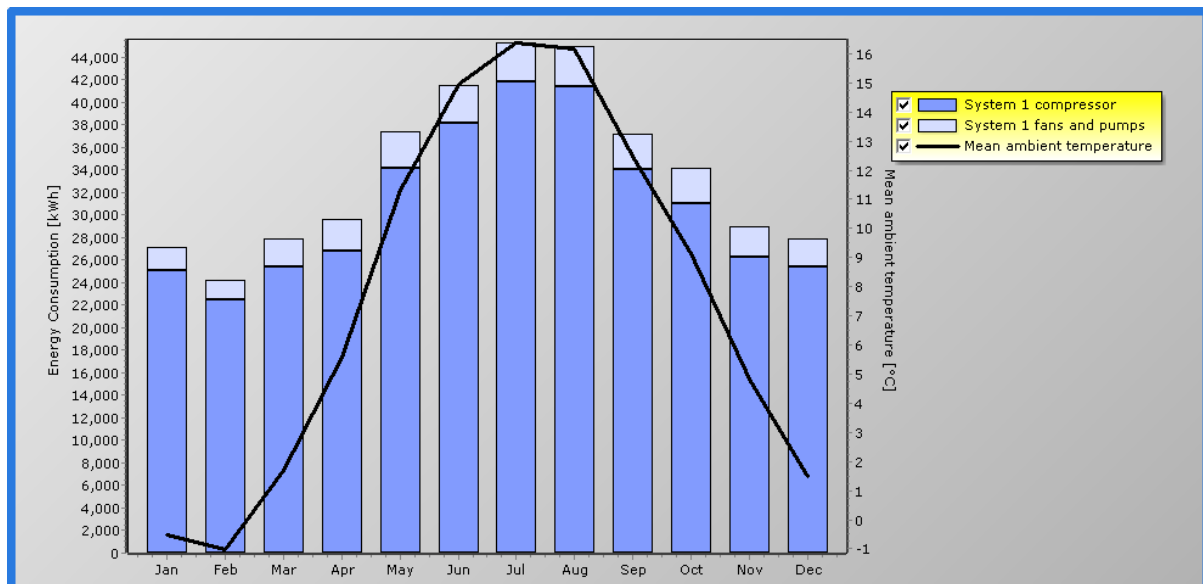
The location can be chosen from 703 different cities all over the world. Each location is represented by a dataset containing hourly values of temperature and relative humidity throughout the year.

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

The calculation is basically running according to the following scheme:

- In a given hour, the ambient temperature, the load (from the load profile) and the evaporation temperature is 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 and 1 compressor on gives 6 kW and two compressors 12 kW then within the given hour, the compressor pack has been running with 1 compressor in 20 minutes and 2 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:



Which shows the monthly energy consumption of compressors and condenser fans and pumps if any.

Looking at the Summary tab, you'll see the following table:

	System 1 (reference)
Load fulfillment in % of time	
LT:	100.0
MT:	100.0
Total:	100.0
Load fulfillment in % of energy	
LT:	100.0
MT:	100.0
Total:	100.0
Average COP	
LT [-]:	5.67
MT [-]:	3.96
Total [-]:	2.97
Pumps and fans energy consumption	
LT [kWh]:	772
MT [kWh]:	33,250
Total [kWh]:	34,022
Compressor energy consumption	
LT [kWh]:	81,710
MT [kWh]:	290,396
Total [kWh]:	372,106
Total energy consumption	
LT [kWh]:	82,482
MT [kWh]:	323,646
Total [kWh]:	406,128
Savings	
Yearly energy savings [kWh]:	-
Yearly energy savings [%]:	-

Which will contain a column for each system you choose to add to your project.

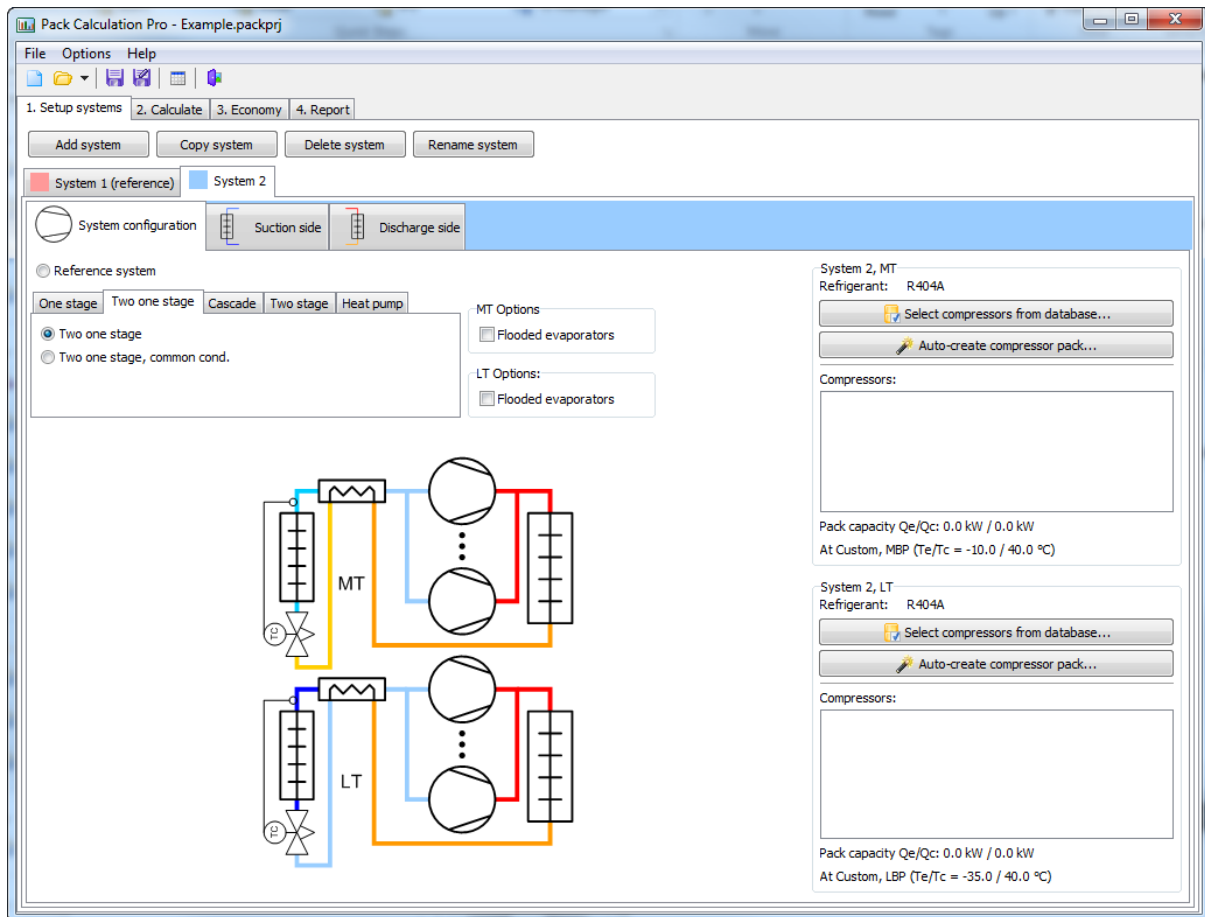
3.4 Adding another system

Looking at the results in the summary table, you will 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, then you should be very careful defining the both the load profile and the temperature profiles!

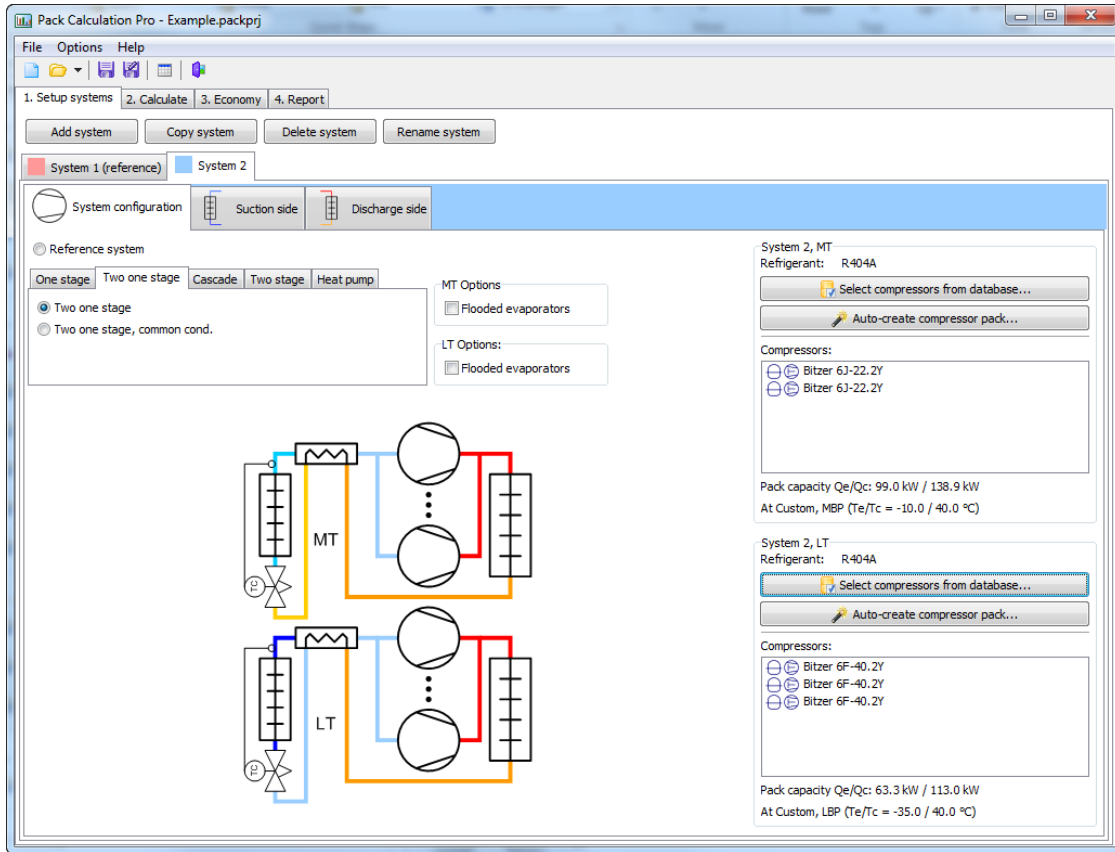
On the other hand, if you at this point add another system and compare the energy consumption between the two, then the difference in percent will probably be a much more realistic value – i.e. no matter what the absolute energy consumption of the two systems is, the difference in percent will be quite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

You can for example compare the CO2 system above with two single stage systems:

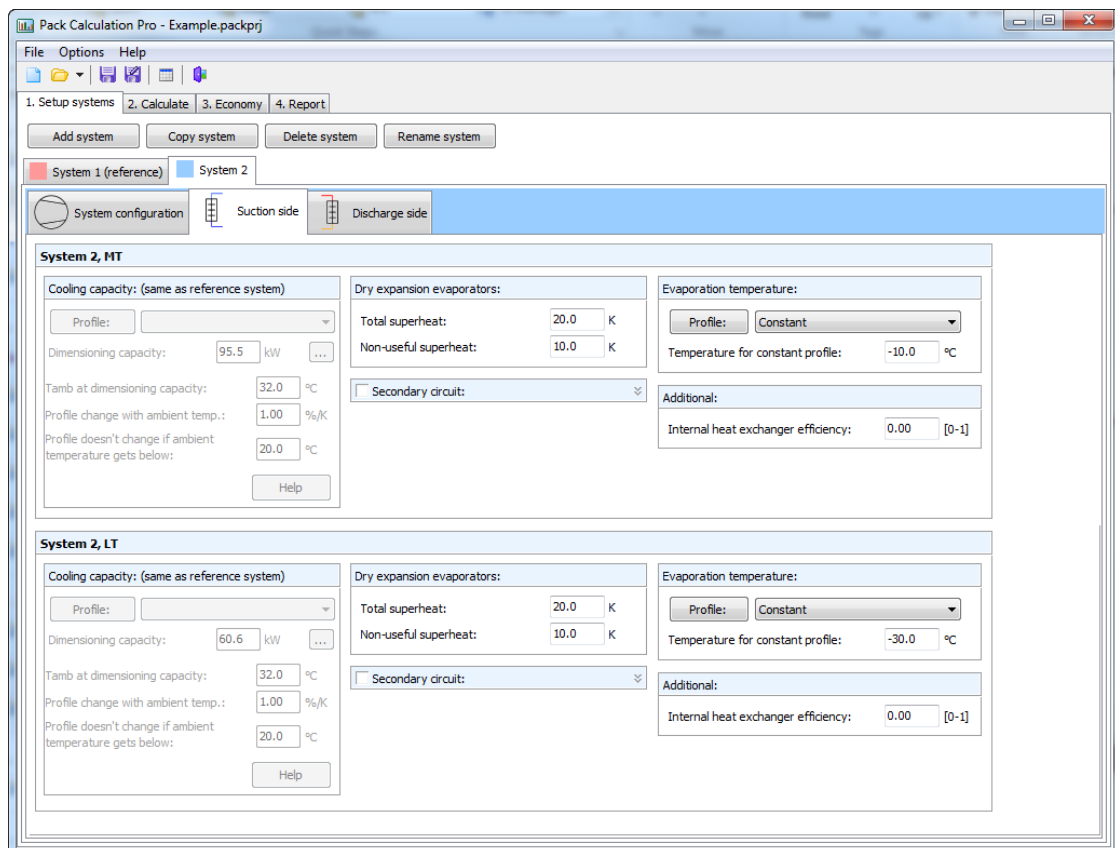
Press [Add System] and select a “Two one stage” system:



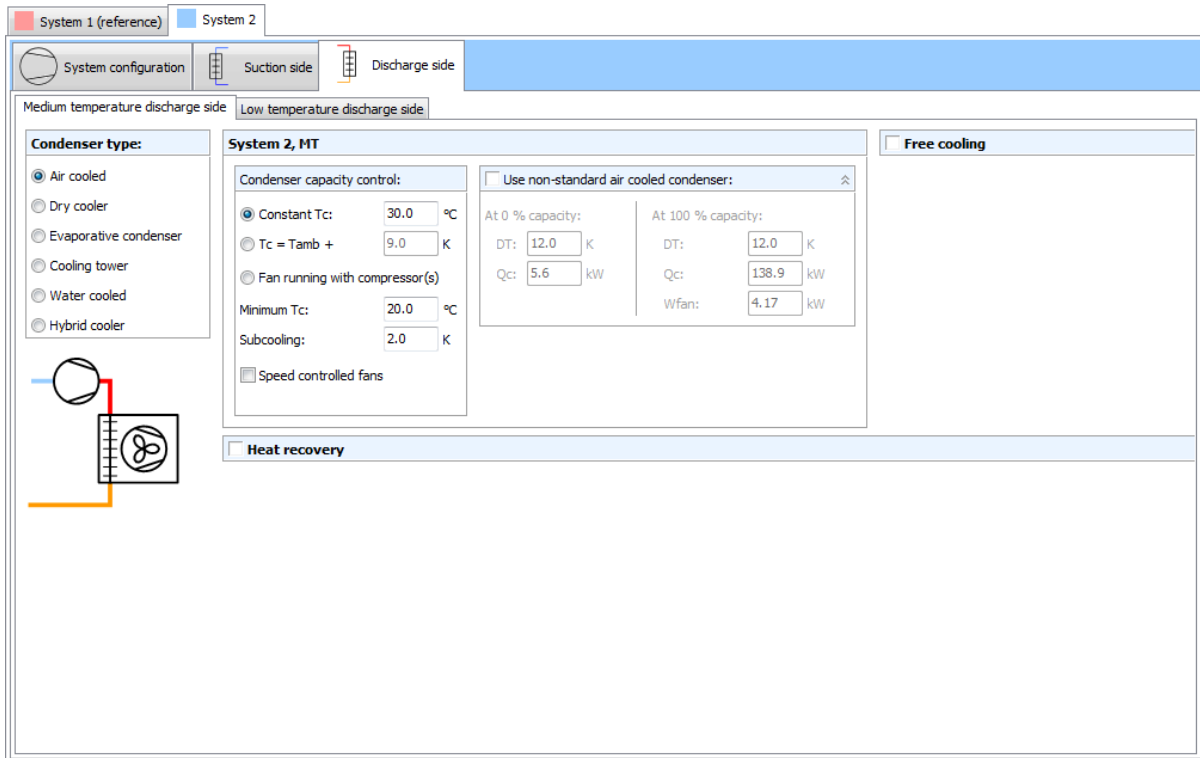
For now, we'll select compressors from database (other options will be covered in chapter 5), remembering that the dimensioning cooling capacity (to be comparable with the system 1) shall be about 60 kW on LT and 96 kW on MT:



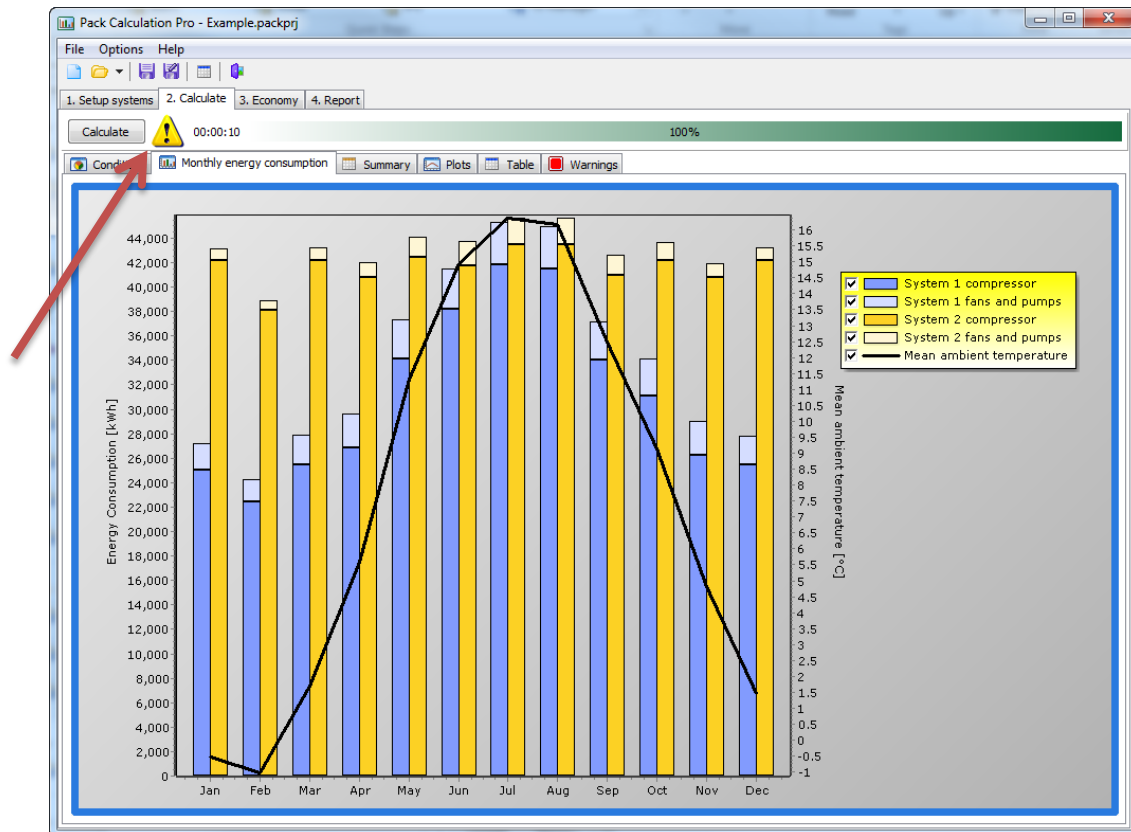
The suction side of System 2 is very simple as the load profile is automatically chosen to be the same as for the reference system:



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):



But then you are ready to calculate, and get the following result:



Note that there is a warning sign shown beside the calculate button – if you click on the sign, you’ll see that the warning occurs because System 2 cannot deliver the needed cooling in 3 hours on August 1st.

If you look at the Summary page, you can get an overview of the yearly difference between the two systems:

	System 1 (reference)	System 2
Load fulfillment in % of time		
LT:	100.0	100.0
MT:	100.0	100.0
Total:	100.0	100.0
Load fulfillment in % of energy		
LT:	100.0	100.0
MT:	100.0	100.0
Total:	100.0	100.0
Average COP		
LT [-]:	5.67	1.70
MT [-]:	3.96	2.88
Total [-]:	2.97	2.27
Pumps and fans energy consumption		
LT [kWh]:	772	12,828
MT [kWh]:	33,250	17,282
Total [kWh]:	34,022	30,110
Compressor energy consumption		
LT [kWh]:	81,710	261,784
MT [kWh]:	290,396	238,535
Total [kWh]:	372,106	500,320
Total energy consumption		
LT [kWh]:	82,482	274,612
MT [kWh]:	323,646	255,817
Total [kWh]:	406,128	530,429
Savings		
Yearly energy savings [kWh]:	-	-124,301
Yearly energy savings [%]:	-	-30.6

The main conclusion of this simulation is that:

“Two one stage systems with constant condensation temperature control will use about 30% 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 COP’s in PackCalc in the summary table is defined as:

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

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

4 Systems

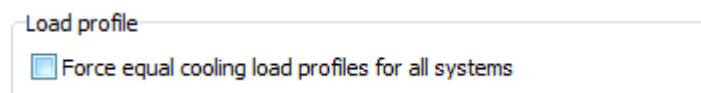
Pack Calculation Pro contains models of 11 refrigeration system configurations and 1 heat pump.

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

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

All of the two stage 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 have to specify the medium temperature, for example as -10 °C.

PackCalc will allow you to compare 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 the internal heat exchanger and flooded evaporator, most systems can be extended with a secondary circuit (see chapter 6.1.4).

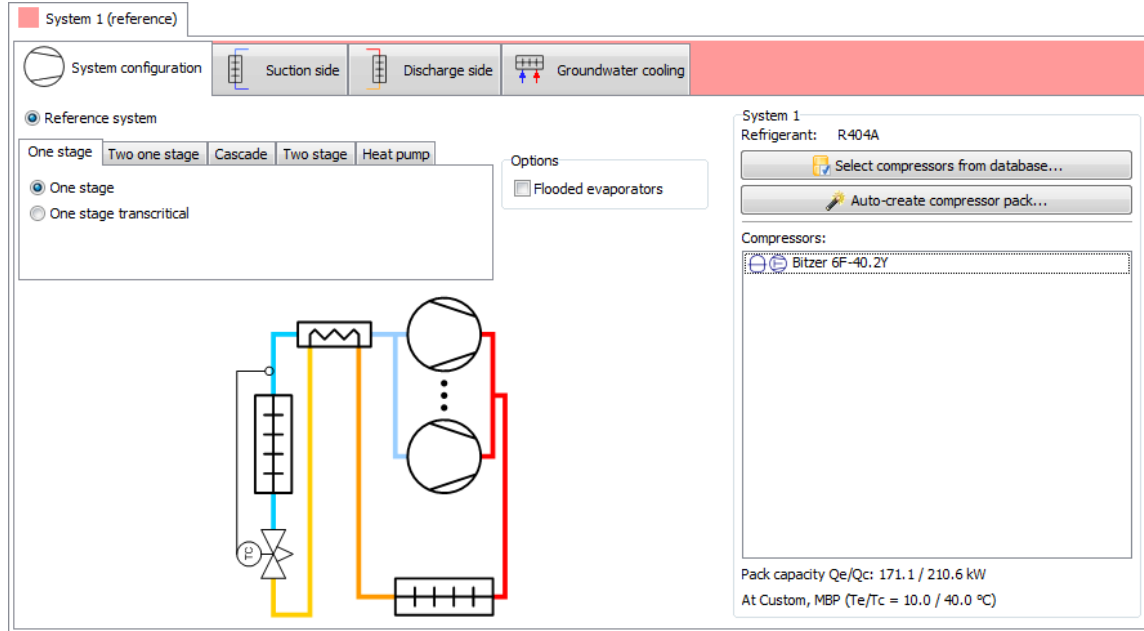
The buttons on top of the “Setup systems” page will allow you to:

- 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”

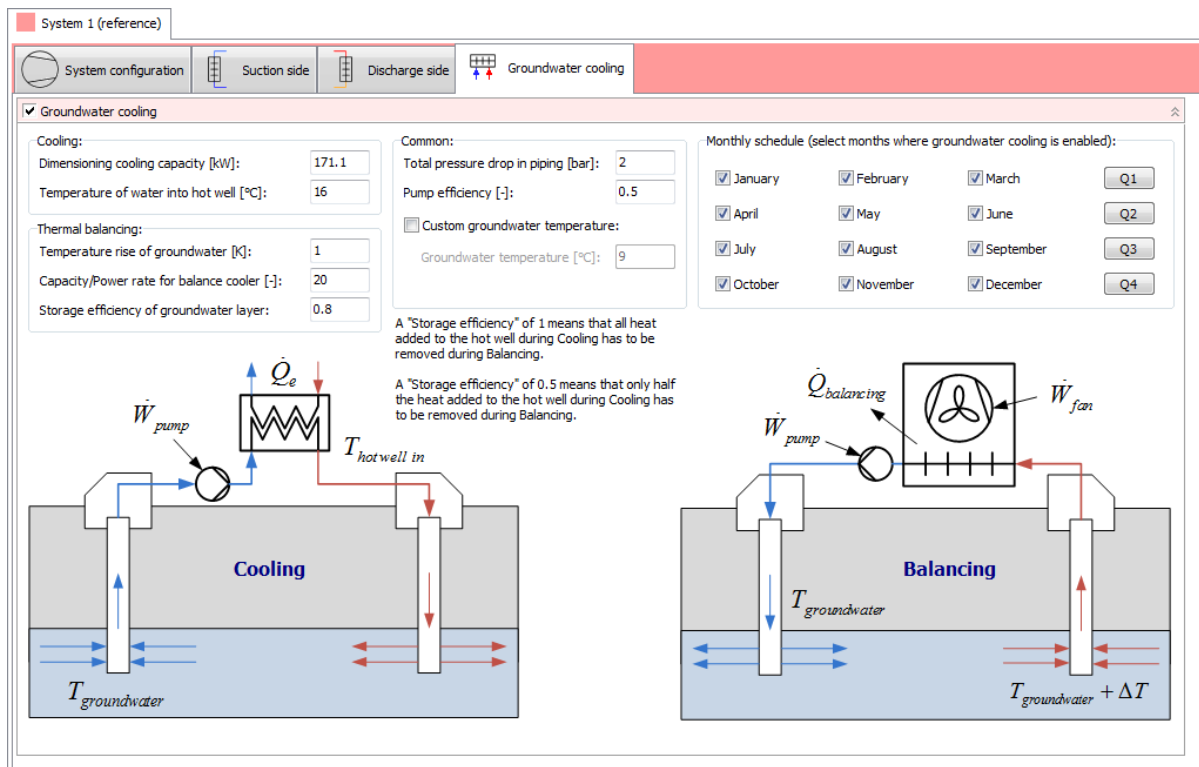
4.1 Groundwater cooling

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:



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

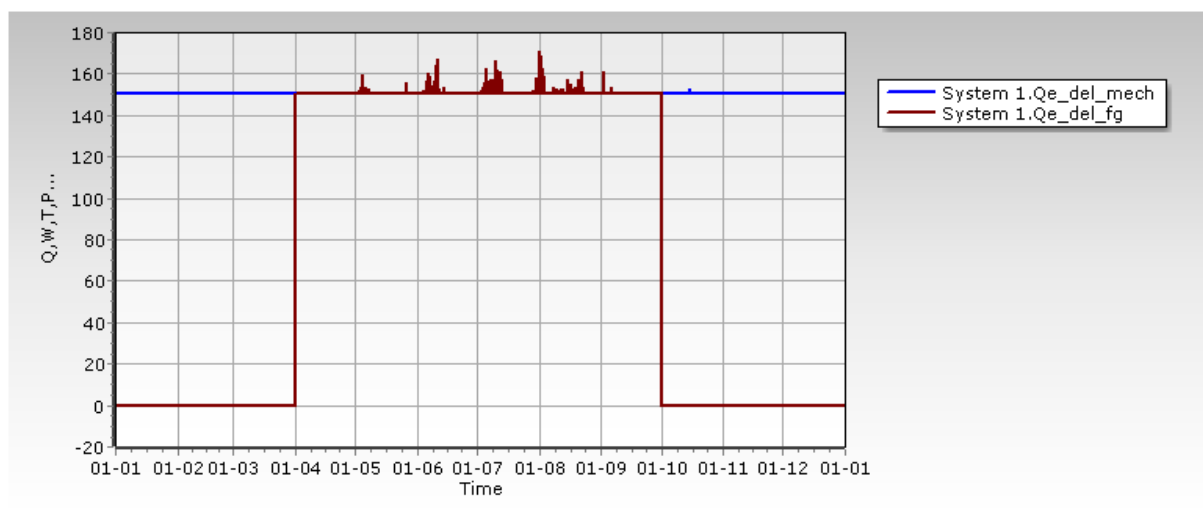


Note that as default, the dimensioning cooling capacity is automatically set to the same value (taken from the dimensioning cooling capacity of the mechanical refrigeration system).

The simulation of the groundwater cooling system is somewhat simplified:

1. Thermal balancing is always performed. PackCalc automatically calculates the necessary energy consumption of fans and pumps for doing the thermal balancing. Whether or not there is actually 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 is requiring an evaporation temperature of -10 °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 °C), then you can inspect the delivered cooling on the Calculate | Plots page:



- Qe_del_mech is the delivered mechanical cooling which is only active in the winter months
- Qe_del_fg is the free cooling + groundwater cooling (which in this case is only groundwater cooling)

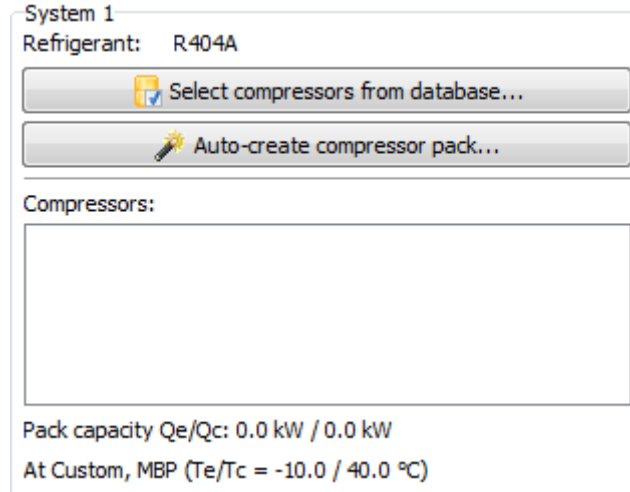
The summary page will contain all the details about the groundwater cooling:

	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 ³ /year]:	69,254
Balancing [m ³ /year]:	456,745
Total [m ³ /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.

5 Compressor definition in details

For some refrigerants and systems, you have the option of defining the compressor pack either by selecting between commercial available compressors from the accompanying database, or by auto-create a compressor:



System 1
Refrigerant: R404A

Select compressors from database...

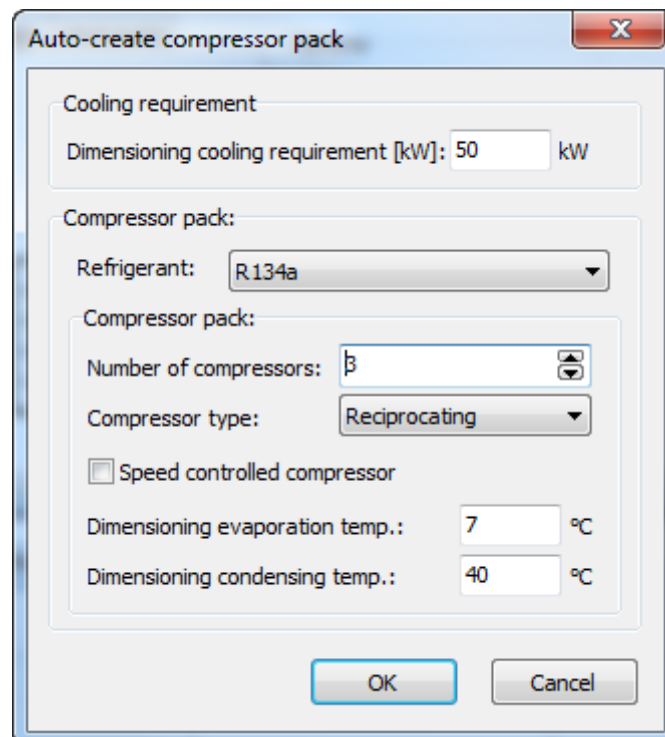
Auto-create compressor pack...

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)

5.1 Auto-creating a compressor

When you press [Auto-create compressor pack] you get the following options:



Auto-create compressor pack

Cooling requirement

Dimensioning cooling requirement [kW]: 50 kW

Compressor pack:

Refrigerant: R134a

Compressor pack:

Number of compressors: 3

Compressor type: Reciprocating

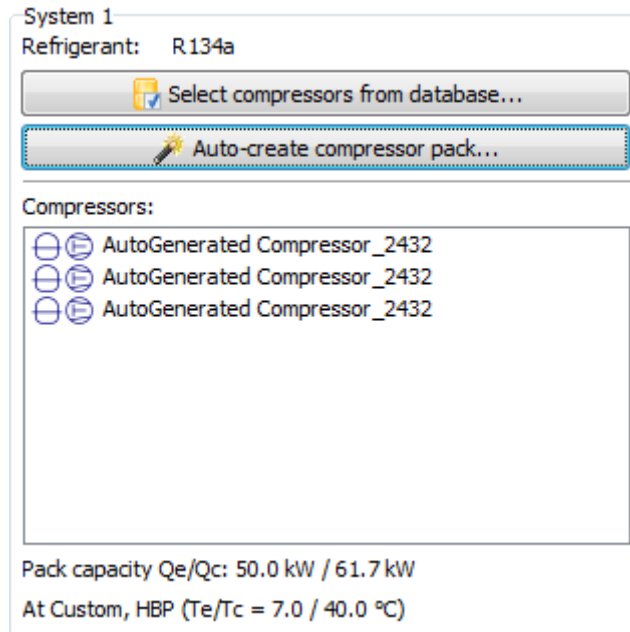
Speed controlled compressor

Dimensioning evaporation temp.: 7 °C

Dimensioning condensing temp.: 40 °C

OK Cancel

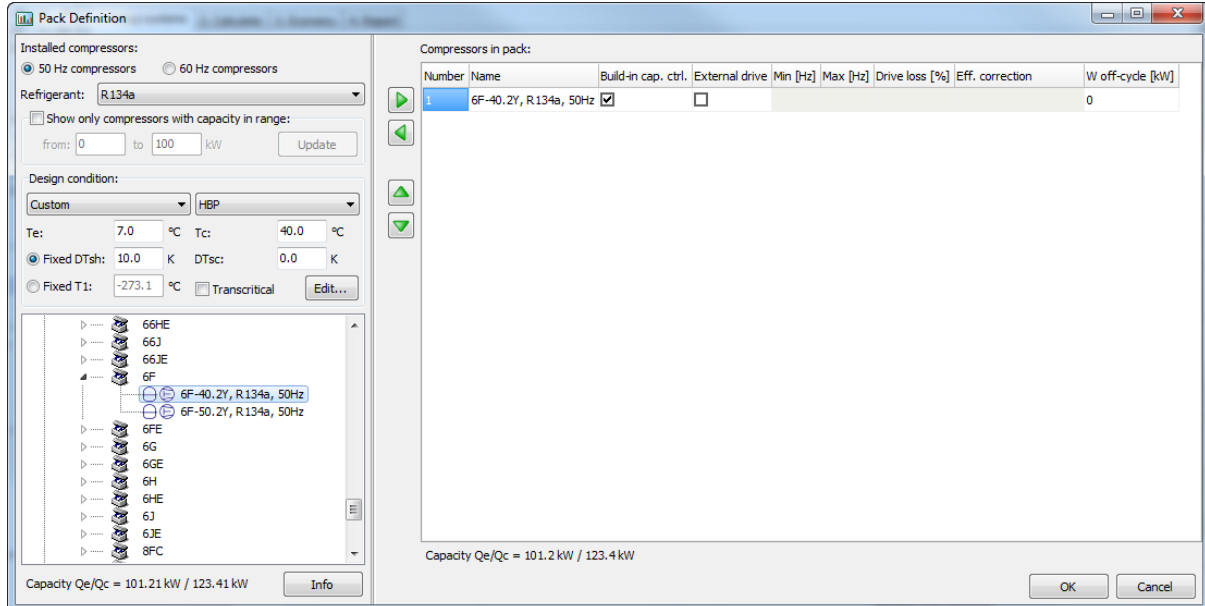
First you select the dimensioning cooling capacity, and then depending on the refrigerant selected, you have the option of selecting between reciprocating (piston), scroll or screw compressor. PackCalc contains generic models of “typical” compressors (including speed control) of the mentioned type for the refrigerants listed in the drop-down. Based on the dimensioning evaporation and condensation temperature, the capacity and the number of compressors, a compressor pack is created automatically:



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

5.2 Selecting from compressor database

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.

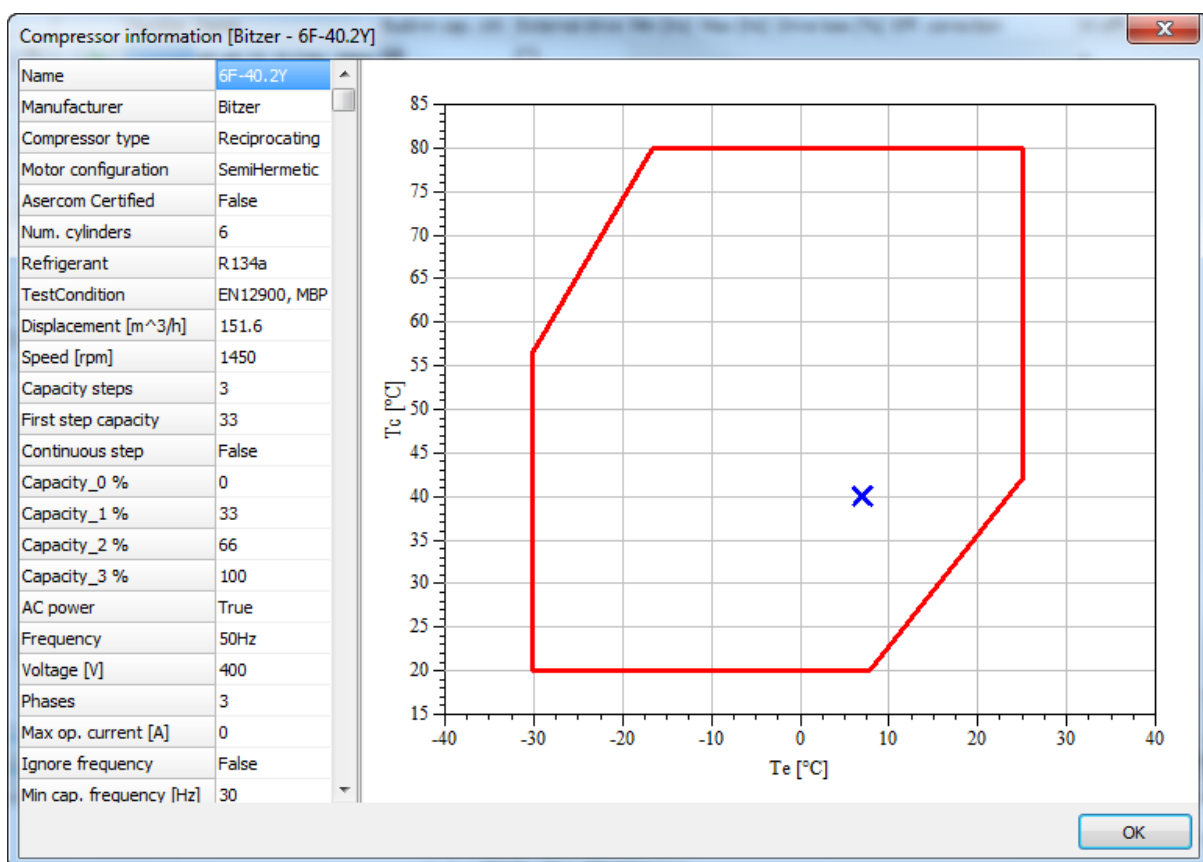
You should select a design condition which is as close as possible to your expected dimensioning conditions. If you for example design a system for use in a supermarket in Dubai at medium temperature, and you select the design condition to $T_e = -10\text{ °C}$ and $T_c = 25\text{ °C}$ and you want 100 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 °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 6.1.1 and 7.2.1), so getting the design condition right, will help producing good simulations.

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 in the tree:



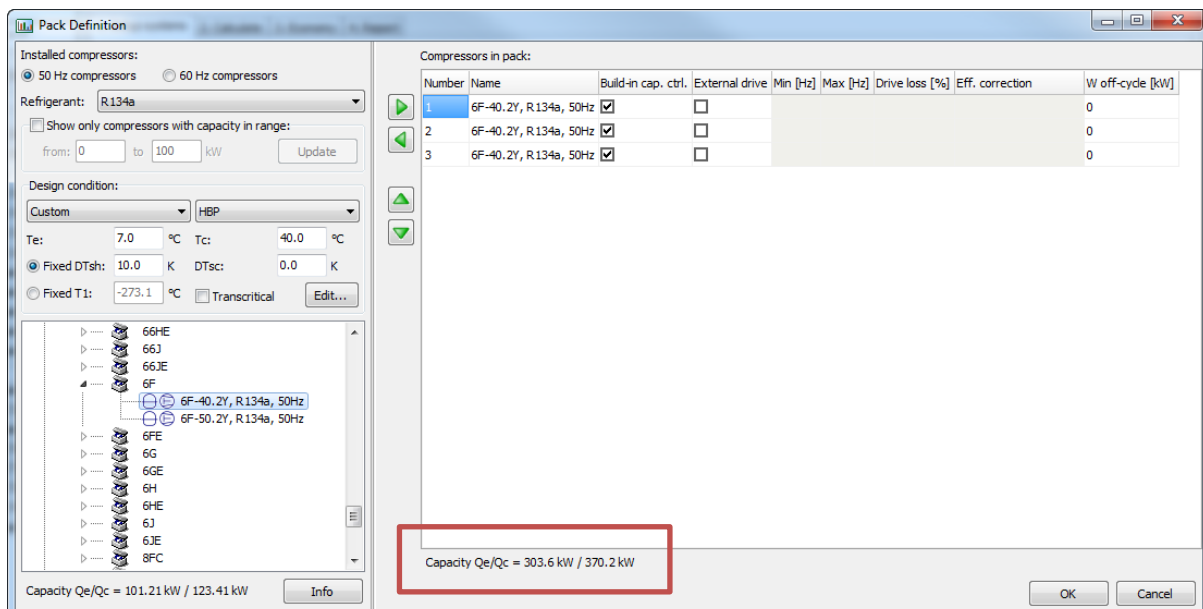
This can be used to check where your design condition is located in the operating envelope for the compressor.

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

- **Build-in cap. ctrl.** If selected then the build-in capacity control of the compressor is used. Examples of build-in capacity controls are cylinder unloading, slide control and also speed control (if the compressor is sold together with a variable speed drive). If this option is grayed, then there is no build-in capacity control (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 build-in capacity control of the compressor is a variable speed drive (and you cannot add an external drive to a build-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:



If it's a one stage refrigeration system you create, then the capacities are used for:

- 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 6.1.5):

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 Qe: 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>DT: 10.0 K</p> <p>Qe: 0.0 kW</p>	<p>At 100 % capacity:</p> <p>DT: 10.0 K</p> <p style="border: 2px solid red; padding: 2px;">Qe: 303.6 kW</p> <p>W: 9.11 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.

5.3 Capacity control

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

5.3.1 On-off compressors pack

If the pack only contains compressors which are turned on/off (this includes cylinder unloading) then calculation is done like this:

- 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:

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

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.

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

5.3.2 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.

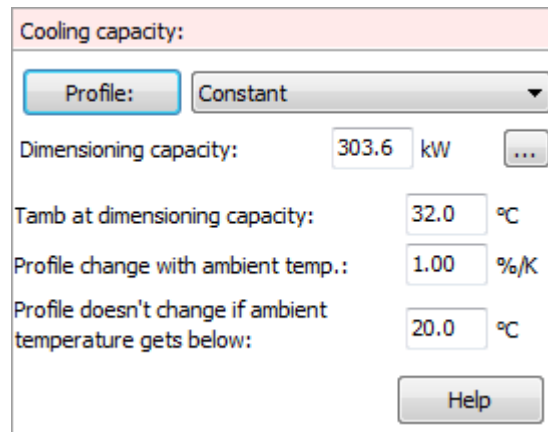
6 Suction side in details

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

6.1 Refrigeration system

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

6.1.1 Cooling capacity



Cooling capacity:

Profile: Constant

Dimensioning capacity: 303.6 kW

Tamb at dimensioning capacity: 32.0 °C

Profile change with ambient temp.: 1.00 %/K

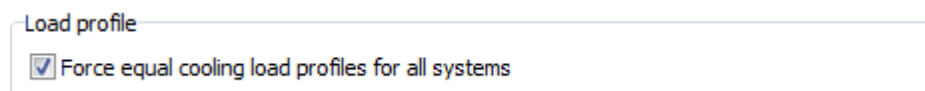
Profile doesn't change if ambient temperature gets below: 20.0 °C

Help

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 below).
- **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.
- **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).

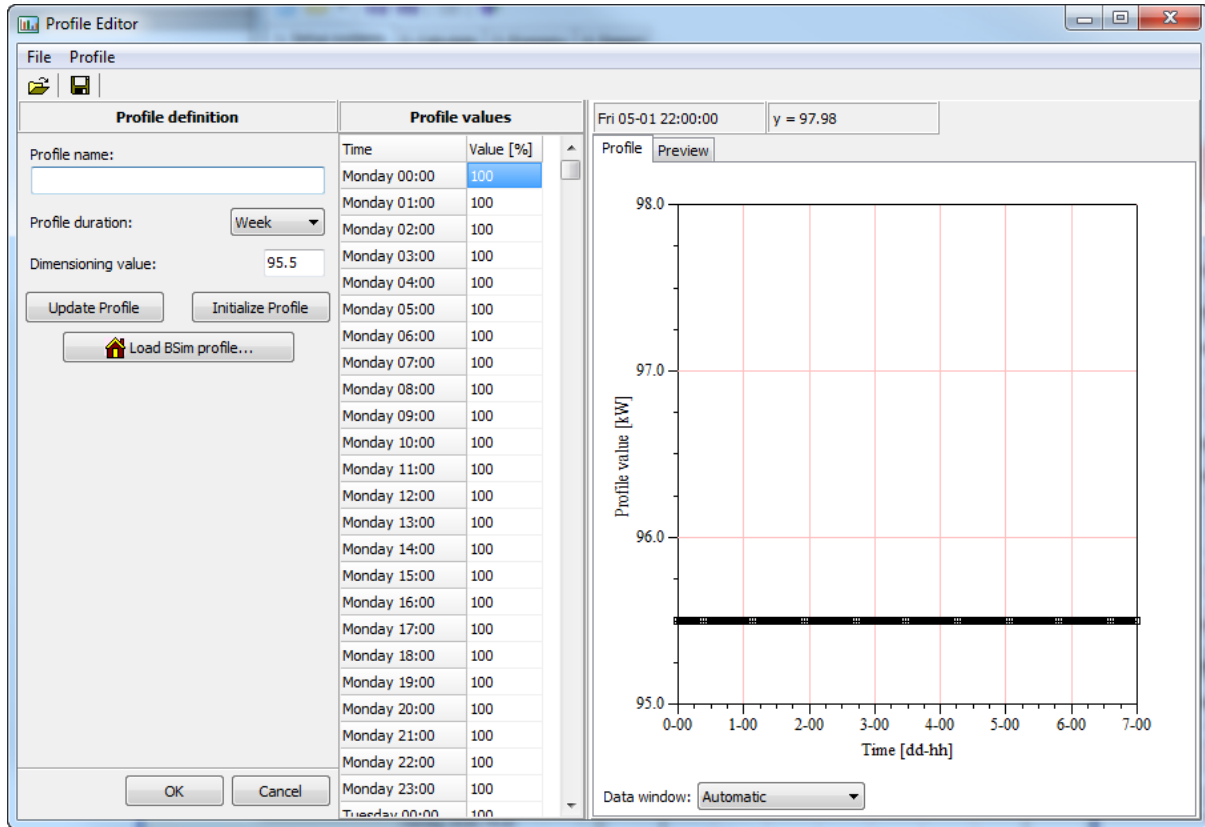
You can (normally) only change the cooling capacity section for the reference system – i.e. the program enforces use of the same load profile for all systems you compare. If you want to compare systems with different load profiles, you should deselect the following option in Options | Preferences | Calculation | 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.

The profile is always relative, and scaled according to the dimensioning value.

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.

6.1.2 Dry expansion evaporators

Dry expansion evaporators:	
Total superheat:	<input type="text" value="20.0"/> K
Non-useful superheat:	<input type="text" value="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 added to the superheat in the evaporator, gives the total superheat. The suction temperature at the compressor pack equals the evaporation temperature plus the total superheat.

6.1.3 Flooded evaporators

Flooded evaporators:

Forced circulation:

Nominal pump power: kW ...

Power proportional to capacity

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).

6.1.4 Secondary circuit

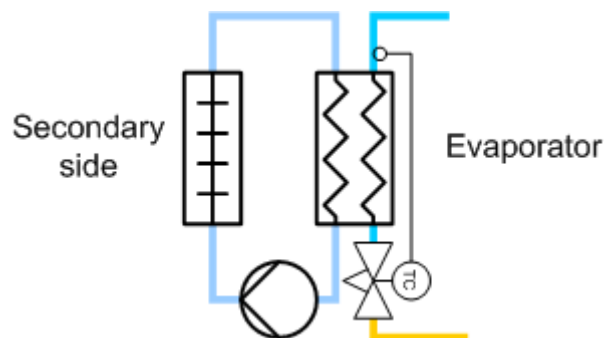
Secondary circuit: ⤴

Secondary pump power: kW

Power proportional to capacity

Constant power

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

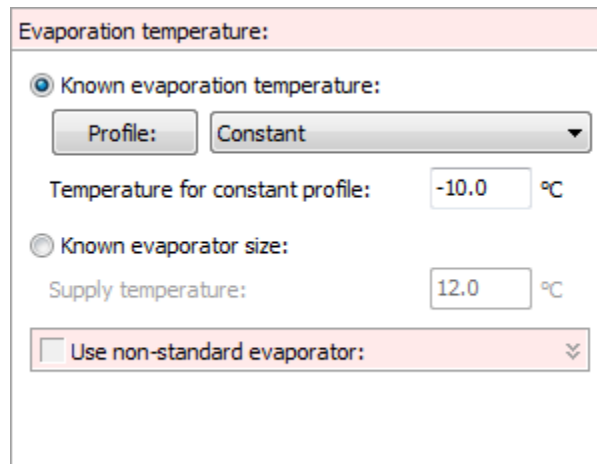


And if you select a secondary circuit, you will include pump power in the total energy consumption.

Note that secondary circuits are not enabled when “Known evaporator size” is selected (it’s only available for “Known evaporation temperature”). See also chapter 6.1.5.

6.1.5 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 the rest of the systems, 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

This means that 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 PackCalc include savings due to the fact that you are able to raise the evaporation temperature during low load situations... 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 D).

6.1.5.1 *Known evaporation temperature*

If you select “Known evaporation temperature” you have to 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.

6.1.5.2 *Known evaporator size*

If you select “Known evaporator size” you shall 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 8).

6.1.6 **Additional**

The additional section will contain additional input options depending on the selected system.

For all systems “Internal heat exchanger efficiency” will be 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
Cascade	Cascade temperature diff	Temperature difference between condensation temperature of LT system and evaporation temperature of MT system
Cascade transcritical	Cascade temperature diff	See above
Cascade CO2	CO2 pump power	Power of CO2 pump
	Cascade temperature diff	See above
Two stage closed intercooler	Intercooler heat exchanger efficiency	Thermal efficiency of intercooler heat exchanger see also appendix A

6.2 Heat pumps

For heat pumps, the suction side will contain the following elements:

6.2.1 Evaporator capacity control

Evaporator capacity control:

Constant Te: °C

Te = Tamb - K

Fan/pump running with compressor(s)

Maximum Te: °C

Total superheat: K

Non-useful superheat: K

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...** where the fans and/or pumps are running full speed whenever the compressors are running.

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 control...** which will apply speed control to fans/pumps (see also appendix B).

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

6.2.2 Additional

Additional	
<input checked="" type="radio"/> Ground source heat pump	
<input type="radio"/> Air source heat pump	
Internal heat exchanger efficiency:	<input type="text" value="0.40"/> [0-1]

In additional you specify the heat source for the heat pump (either ground or air) and the efficiency of an internal heat exchanger (if none, then set efficiency to 0 – see appendix A)

6.2.3 Non-standard evaporator

Use non-standard evaporator: <input type="checkbox"/>	
At 0 % capacity:	At 100 % capacity:
DT: <input type="text" value="10.0"/> K	DT: <input type="text" value="10.0"/> K
Qe: <input type="text" value="0.0"/> kW	Qe: <input type="text" value="303.6"/> kW
	W: <input type="text" value="9.11"/> kW

As default the evaporator is auto-selected, using the cooling 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 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 Discharge side in details

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

7.1 Refrigeration system

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

- The condenser type – the different types are treated in detail in appendix B, here only air-cooled condenser will be shown.
- The condenser capacity control method
- The size of the condenser
- Plus perhaps 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 then 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 varies 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 varies 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 increase the energy consumption of the system and this increase is not included in PackCalc.

7.1.1 Transcritical condenser control parameters

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, then it is assumed that all fans (and pumps) are running 100% and that this means that 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 the high pressure control settings you can set in a Danfoss EKC 326A controller (see the documentation on www.danfoss.com for details):

- **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.** Decides together with **TC Factor 2** how the controller behaves in transition mode.

7.1.2 Subcritical condenser control parameters

Condenser capacity control:

Constant Tc: °C

Tc = Tamb + K

Fan running with compressor(s)

Minimum Tc: °C

Subcooling: K

Speed controlled fans

If the system is not transcritical, you can select two other condenser capacity control methods (besides $T_c = T_{amb} + b$):

- **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.

7.1.3 Non-standard air cooled condenser

Use non-standard air cooled condenser: ⤴

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.

7.1.4 Free cooling

When enabling free cooling, you should first select the free cooling method:

Free cooling

On/Off 100% free cooling when Tamb <= °C

Start free cooling when Tamb <= °C

Continuous 100% free cooling when Tamb <= °C

Speed controlled fans

Speed controlled pump Supply temperature: °C

Use non-standard free cooler:

At 0 % capacity:		At 100 % capacity:			
DT:	<input type="text" value="10.0"/> K	DT:	<input type="text" value="10.0"/> K	Wfan:	<input type="text" value="2.44"/> kW
Q:	<input type="text" value="3.8"/> kW	Q:	<input type="text" value="95.5"/> kW	Wpump:	<input type="text" value="0.43"/> kW

If you select On/Off then the compressors are turned off when the ambient temperature is below the specified limit. If you choose Continuous, then the program reduces the load linearly from 0 to 100% when the ambient temperature is within the specified limit.

When specifying free cooling, you also need to specify the supply temperature (on the cold side), whether fans and pump are speed controlled and the size of the free cooler. The free cooler is automatically sized from the dimensioning cooling capacity of the selected compressor pack. 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 and the default values can be changed in Options|Preferences.

7.1.5 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:

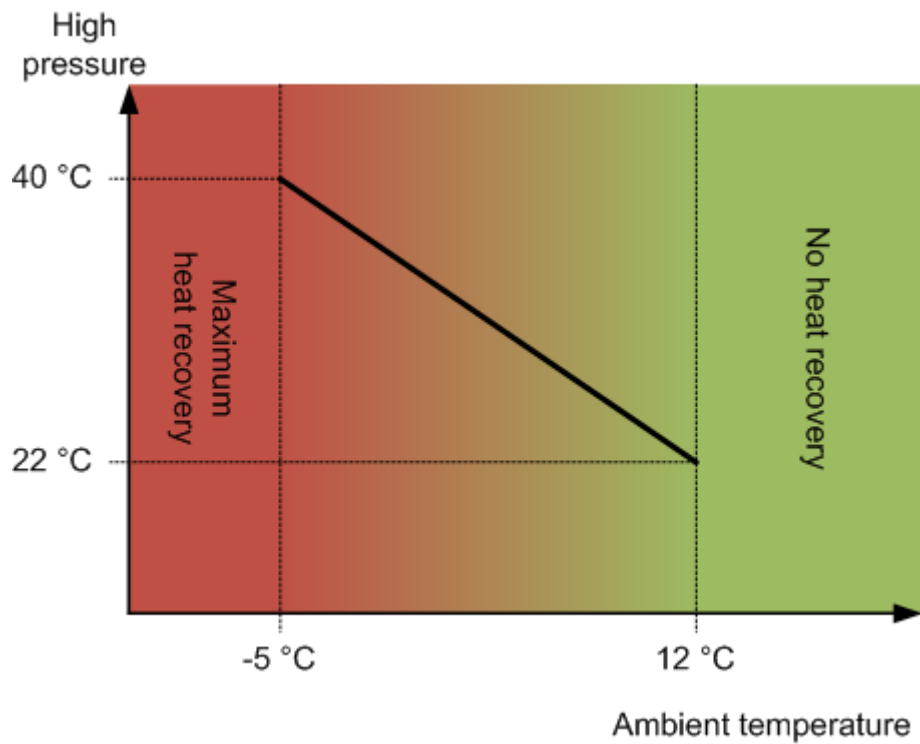
- A function of ambient temperature, where the high pressure (condensation pressure) is varied between the specified start and end temperature according to the specified ambient temperature limits.

- 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):

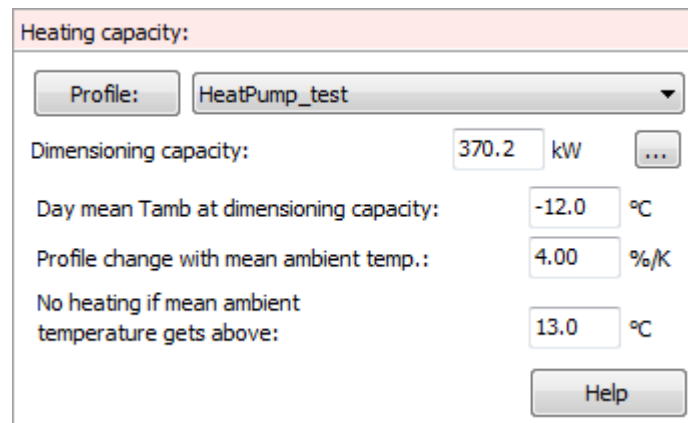


7.2 Heat pump

Defining the discharge side of a heat pump involves:

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

7.2.1 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

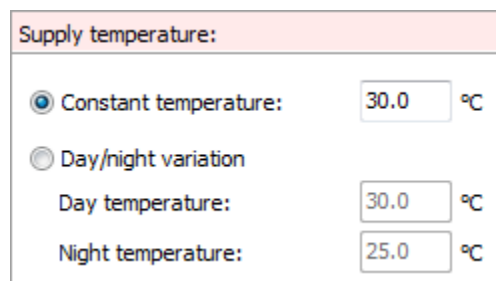
No heating if mean ambient temperature gets above: 13.0 °C

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 exactly 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).

7.2.2 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.

7.2.3 Non-standard condenser

<input type="checkbox"/> Use non-standard condenser:			
DT:	<input type="text" value="5.0"/> K	Qc:	<input type="text" value="370.2"/> kW
Subcooling:	<input type="text" value="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.

8 Results

When all systems have been defined, you are ready to calculate the yearly energy consumption.

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 warning has been raised. If you click on the icon, the warning page will be selected and you can see details about the warning(s).

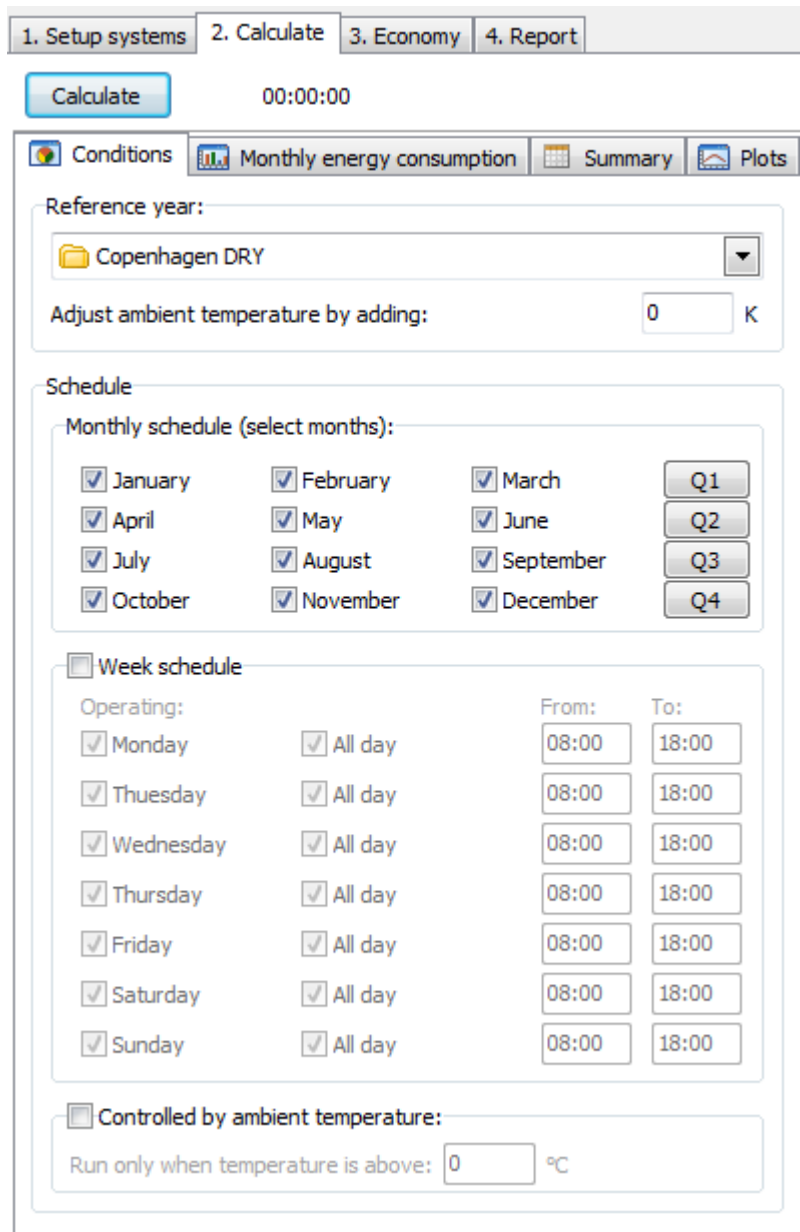


Calculation finished without problems or warnings

The individual pages on the “Calculate” page are explained below.

8.1 Conditions

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



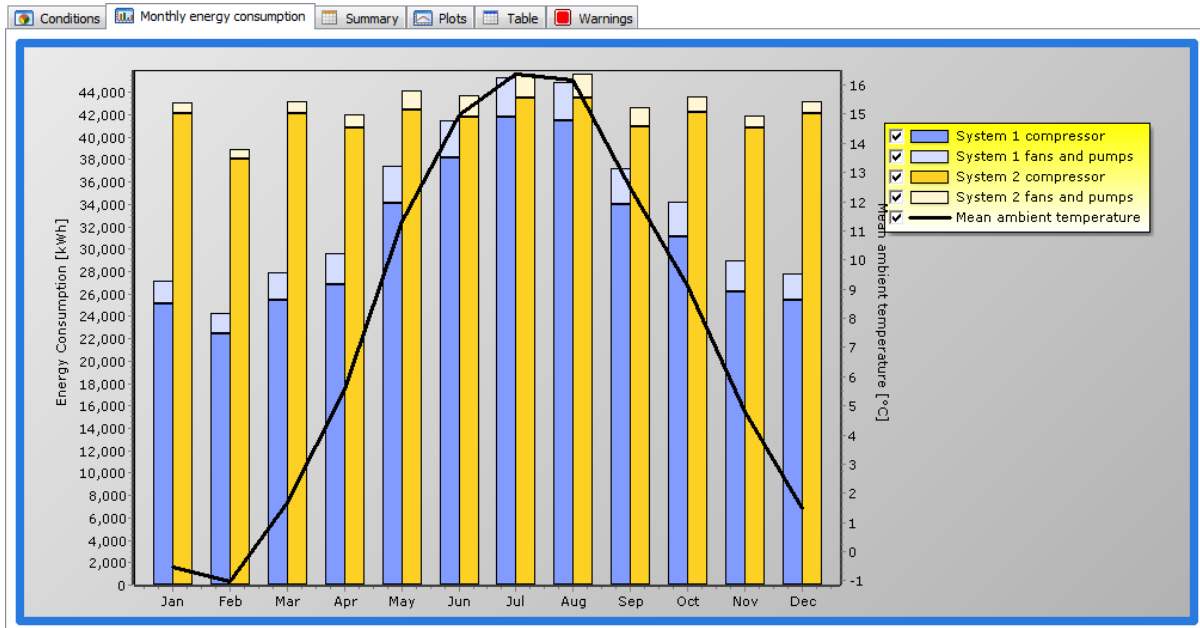
You should first select a reference year. The selection you make will be saved as default when you exit PackCalc.

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.

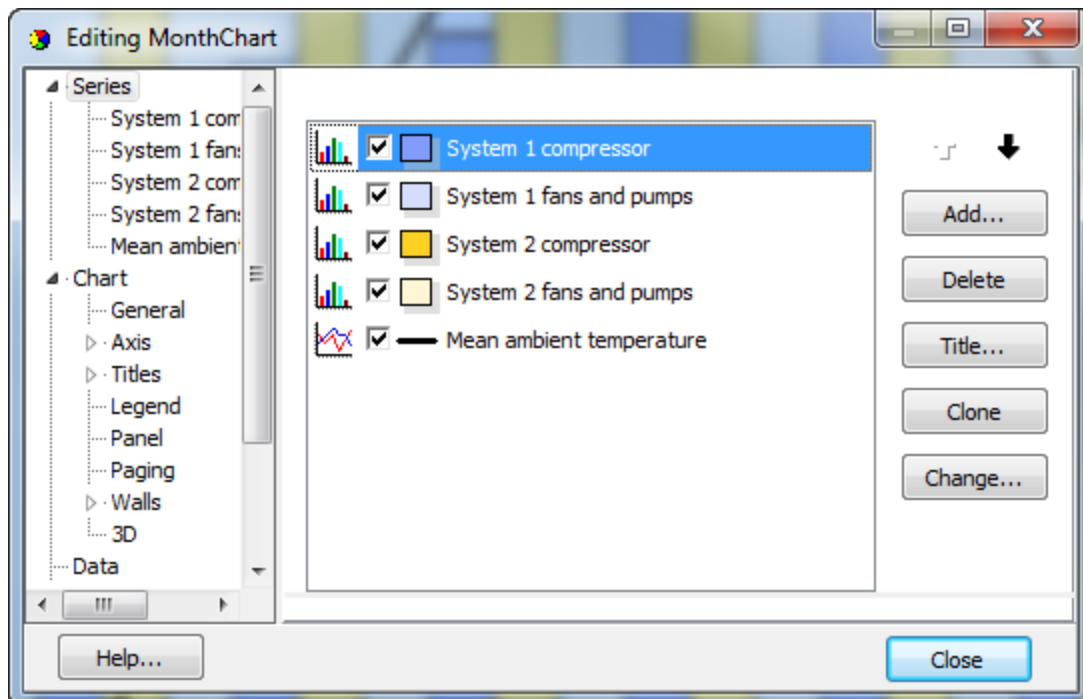
If your system is not running all year, you can define periods where the system is stopped. You can also select a control strategy where the system is only running if the ambient temperature is above a certain value.

8.2 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:



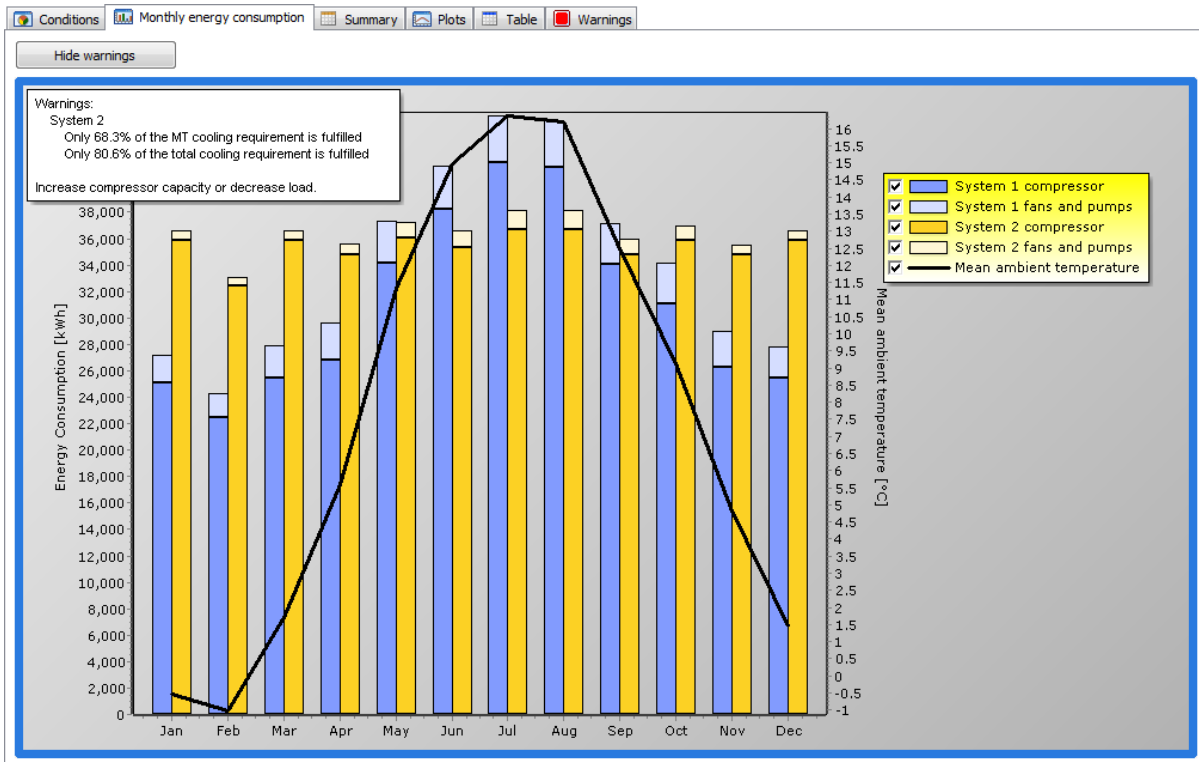
If you double-click on the graph, you will see the following dialog where you can format the graph in details:



If for some reason you have included a system which has insufficient capacity – i.e. is not able to fulfill the required cooling 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 fulfillment (either in respect to time or energy) is less than 99%.

8.3 Summary

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

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


00:00:10

 Conditions
 Monthly energy consumption
 Summary
 Plots

	System 1 (reference)	System 2
Load fulfillment in % of time		
LT:	100.0	100.0
MT:	100.0	100.0
Total:	100.0	100.0
Load fulfillment in % of energy		
LT:	100.0	100.0
MT:	100.0	100.0
Total:	100.0	100.0
Average COP		
LT [-]:	5.67	1.70
MT [-]:	3.96	2.88
Total [-]:	2.97	2.27
Pumps and fans energy consumption		
LT [kWh]:	772	12,828
MT [kWh]:	33,250	17,282
Total [kWh]:	34,022	30,110
Compressor energy consumption		
LT [kWh]:	81,710	261,784
MT [kWh]:	290,396	238,535
Total [kWh]:	372,106	500,320
Total energy consumption		
LT [kWh]:	82,482	274,612
MT [kWh]:	323,646	255,817
Total [kWh]:	406,128	530,429
Savings		
Yearly energy savings [kWh]:	-	-124,301
Yearly energy savings [%]:	-	-30.6

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 COP's in PackCalc in the summary table is defined as:

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

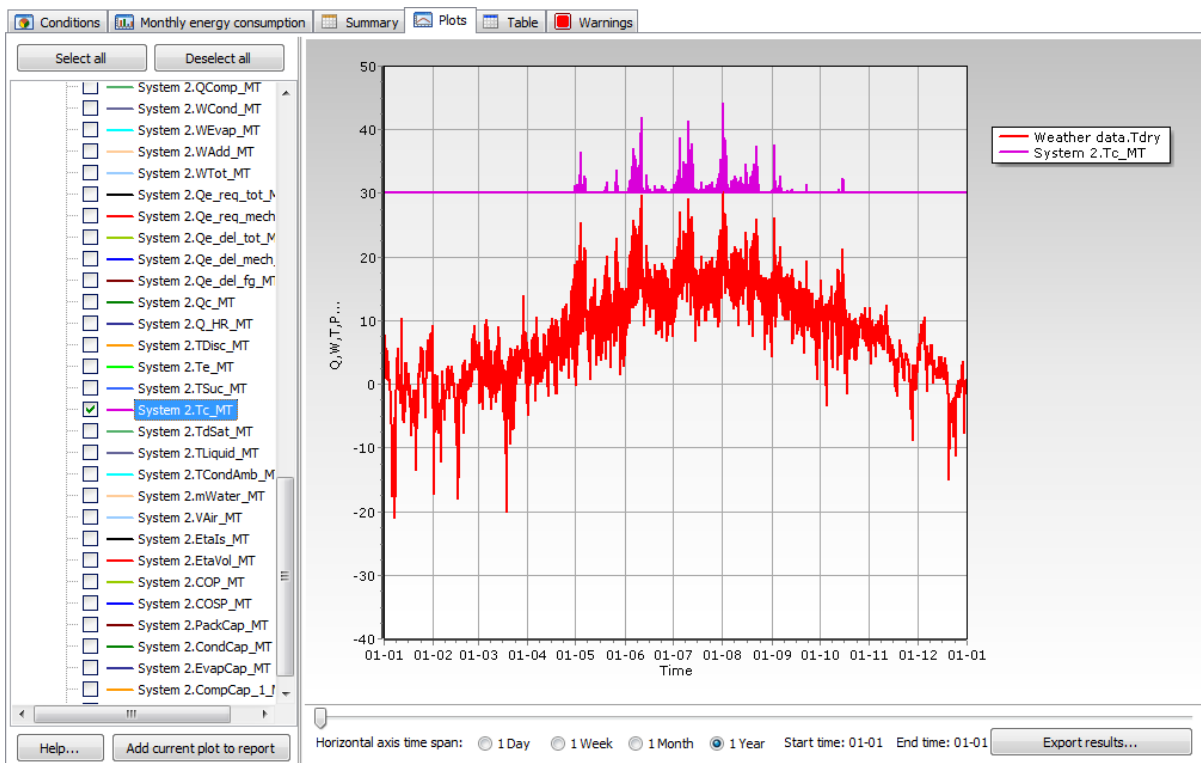
$$COP_{MT} = \frac{Q_{e,tot,MT}}{W_{tot,MT}}$$

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

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

8.4 Plots

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



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 color.

If you click the [Export results] button you can export all curve to a text file (tab-separated columns) which you can easily import into Excel.

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 5.3.1):

- 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.

8.5 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.

8.6 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 fulfill 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..

9 Economy

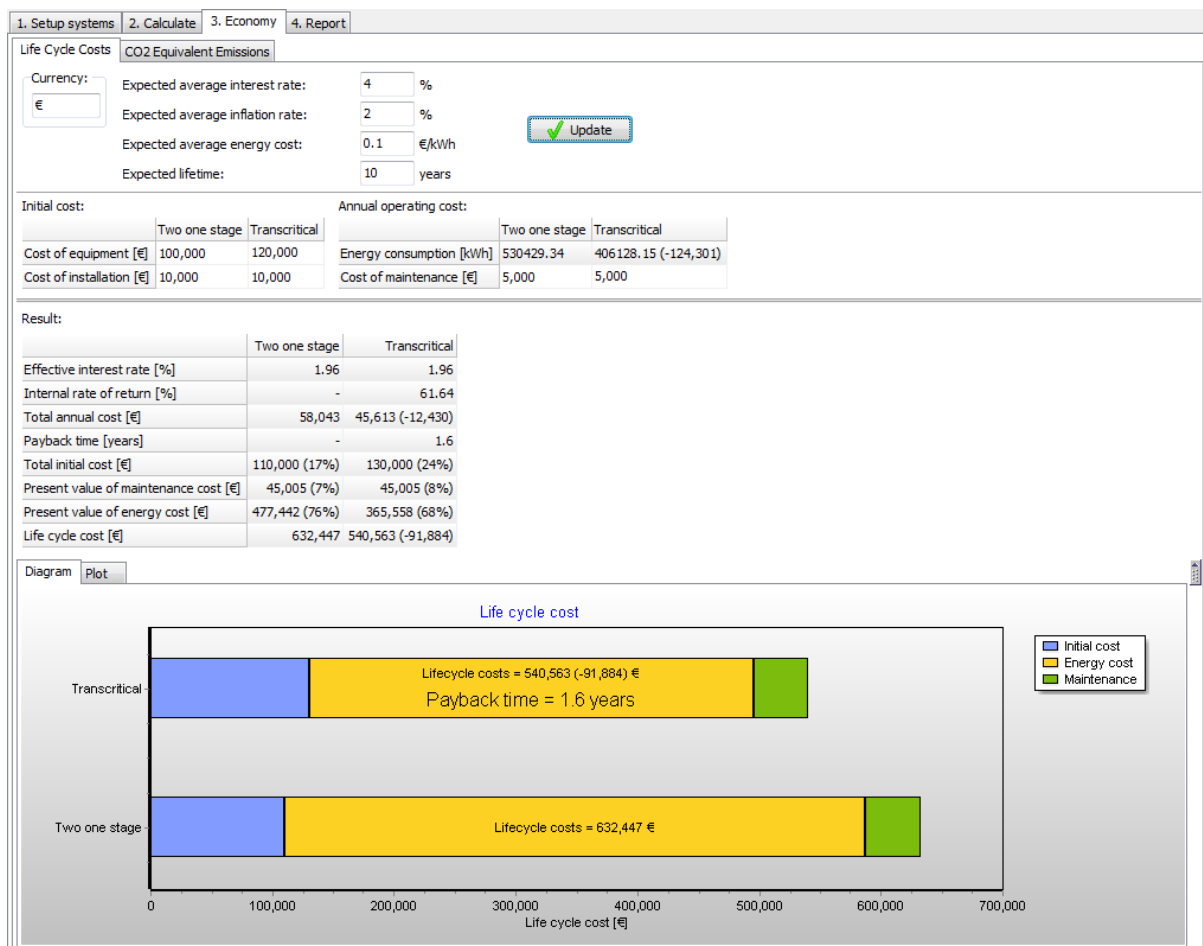
On the economy page you can calculate life cycle costs, payback time and CO2 emissions.

9.1 Life cycle costs

Before calculating the life cycle costs you should specify:

- The currency used (this is just a text – there is no currency conversion included in PackCalc)
- 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 expected average energy costs – i.e. the expected average energy costs 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:

$$\text{Present value} = PWF \cdot \text{Amount}$$

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

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

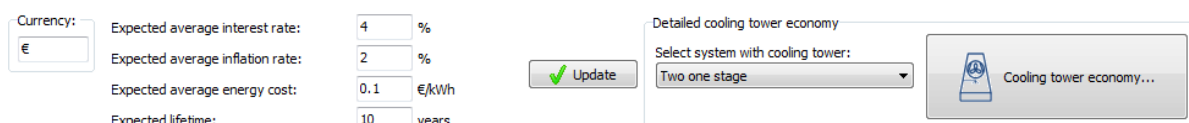
$$\text{Payback} = \frac{\text{Initial costs}_{\text{system}} - \text{Initial costs}_{\text{reference system}}}{\text{Annual costs}_{\text{reference system}} - \text{Annual costs}_{\text{system}}}$$

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).

9.2 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:



The screenshot shows a form with the following elements:

- Currency:** A dropdown menu with '€' selected.
- Expected average interest rate:** A text input field with '4' and a '%' symbol.
- Expected average inflation rate:** A text input field with '2' and a '%' symbol.
- Expected average energy cost:** A text input field with '0.1' and '€/kWh'.
- Expected lifetime:** A text input field with '10' and 'years'.
- Update:** A green button with a checkmark icon.
- Detailed cooling tower economy:** A section containing a dropdown menu labeled 'Select system with cooling tower:' with 'Two one stage' selected, and a button labeled 'Cooling tower economy...' with a cooling tower icon.

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

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: m²

Rainwater tank sizes to calculate:

- Number of tanks:
- Maximum size: m³

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

Tank size [m ³]	Investment costs [€]	Operating costs [€]	Total Present Value [€]
2	1000	40000	41000
4	2000	39000	41000
6	3000	38000	41000
8	4000	37000	41000
10	5000	36000	41000
12	6000	35000	41000
14	7000	34000	41000
16	8000	33000	41000
18	9000	32000	41000
20	10000	31000	41000
22	11000	30000	41000
24	12000	29000	41000
26	13000	28000	41000
28	14000	27000	41000
30	15000	26000	41000

Selected rainwater tank size: m³

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 rain water.

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:

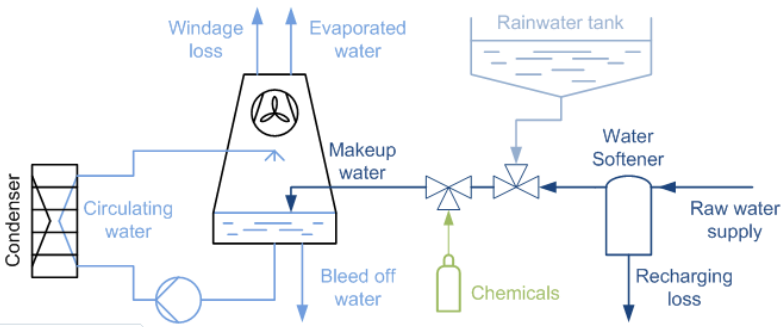
Installation cost: € 10,000.00

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 €/m³

Salt for water softener: 0.2 €/m³ softened water

Chemicals: 1 €/m³ makeup water

Drainage fee: 4 €/m³

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

Buttons: Load prices..., Save prices..., Add price, Delete price, Update, Load default prices, Save as default

Selected rainwater tank size: 4 m³

Buttons: 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).

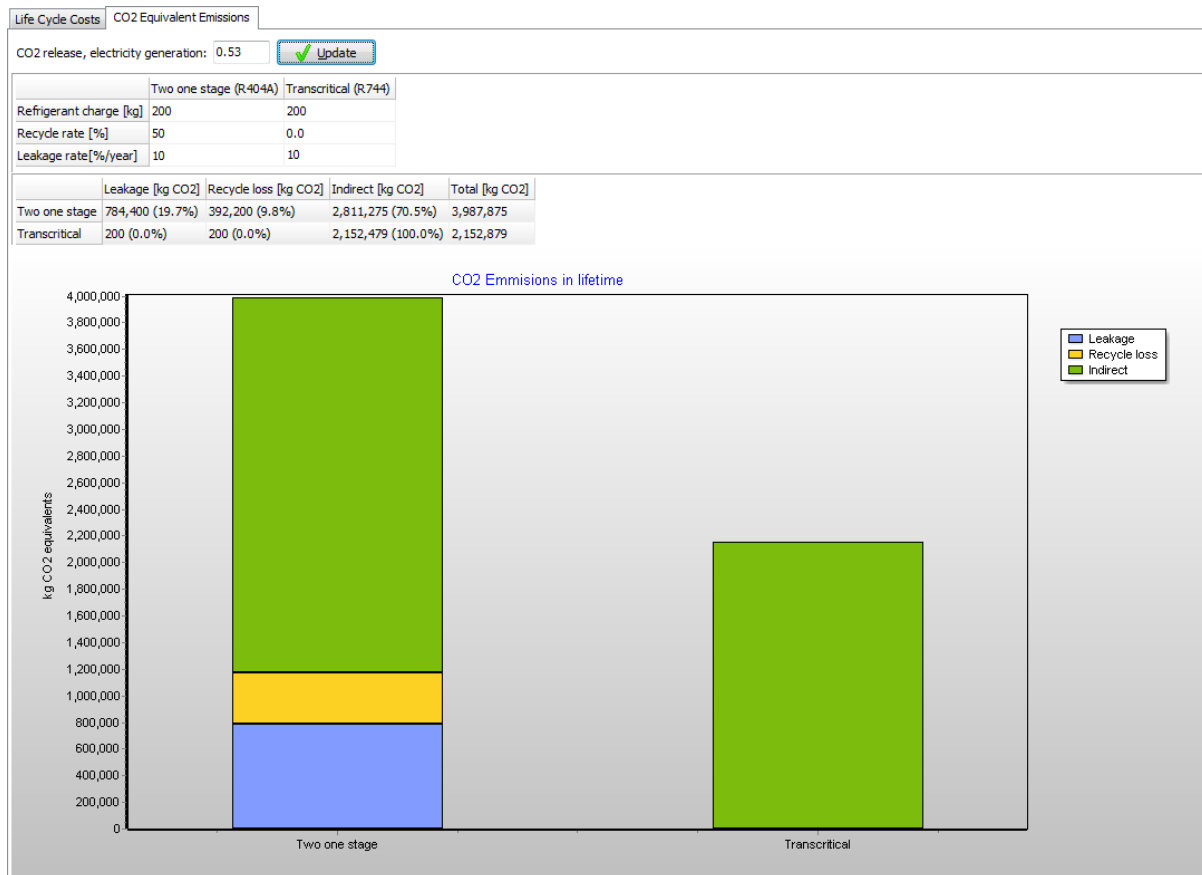
Note also that the default prices for water and rain water tanks are in DKK (the prices shown above reflect approximate Danish prices in €). Note also that you can optionally include drainage fee for all the water that the cooling tower uses (this is sometimes the case) or only include drainage fee for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

9.3 CO₂ emissions

On the “CO₂ equivalent emissions” page you can calculate the equivalent CO₂ emissions for the systems you have defined. The calculation will depend on the following numbers:

- Equivalent CO₂ release from electricity production. This number will depend very much on you location! PackCalc uses this number to calculate indirect emissions – i.e. emissions due to the power consumption of you system.
- The refrigerant charge – PackCalc will automatically calculate equivalent CO₂ emissions due to release of refrigerant (CO₂ equivalents for all supported refrigerants is included in PackCalc):
 - 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 CO₂ emissions in the lifetime of a system could look like this:



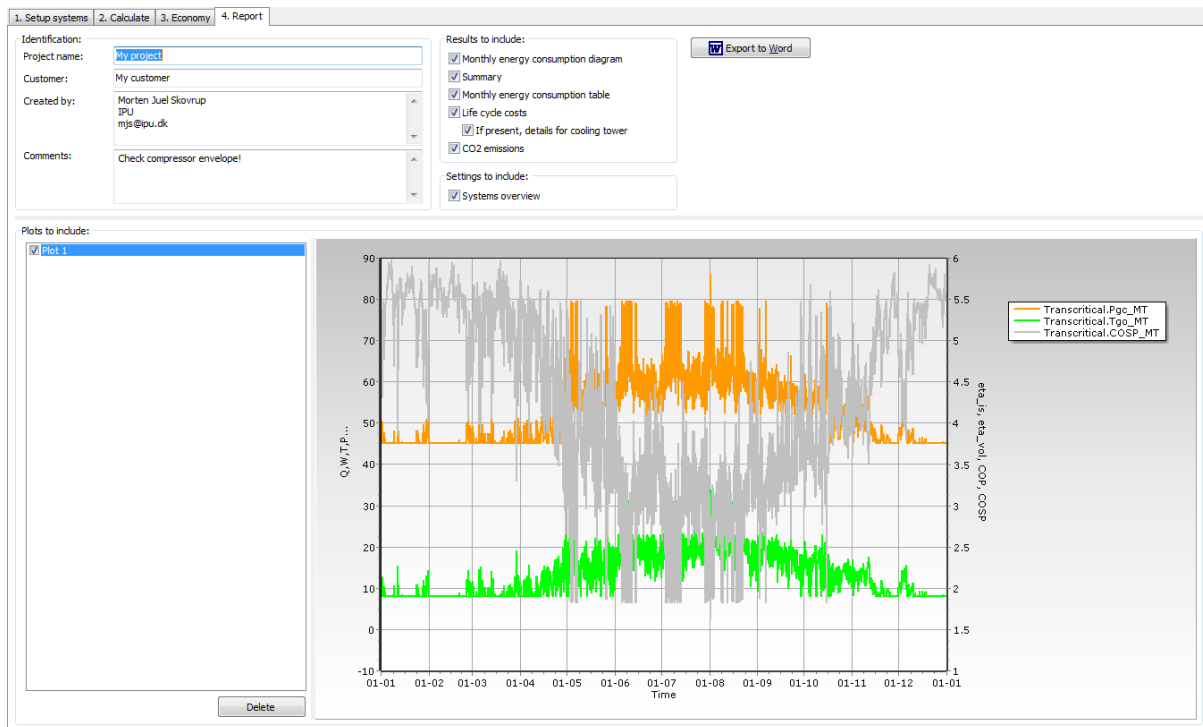
The graph divides the emission into:

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

As can be seen above – for this example – the indirect losses are dominant, while the contribution from leakage and recycle loss is only important for the R404A systems and not for the transcritical systems using CO₂ as refrigerant.

10 Report

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



The screenshot displays the 'Report' configuration window. On the left, the 'Identification' section contains fields for Project name (My project), Customer (My customer), Created by (Morten Juel Skovrup, IPU, mjs@ipu.dk), and Comments (Check compressor envelope!). The 'Results to include' section has checkboxes for Monthly energy consumption diagram, Summary, Monthly energy consumption table, Life cycle costs, IF present, details for cooling tower, and CO2 emissions. The 'Settings to include' section has a checkbox for Systems overview. An 'Export to Word' button is located to the right. Below these sections, the 'Plots to include' list contains 'Plot 1'. The main plot area shows a time-series graph with three data series: Transcritical.Pgc_MT (orange), Transcritical.Tgo_MT (green), and Transcritical.COSP_MT (grey). The x-axis is labeled 'Time' and ranges from 01-01 to 01-01. The left y-axis is labeled 'Q,W,T,P...' and ranges from -10 to 90. The right y-axis is labeled 'eta, eta_vol, COP, CO2P, CO2SP' and ranges from 1 to 6. A 'Delete' button is located below the plot area.

The information that goes into the report is pretty much everything – plots and tables – that you have produced in the simulation.

If you use a personal license, it will be written in the report, while if you have a commercial license you have the possibility to automatically include company logo etc. (see chapter 11).

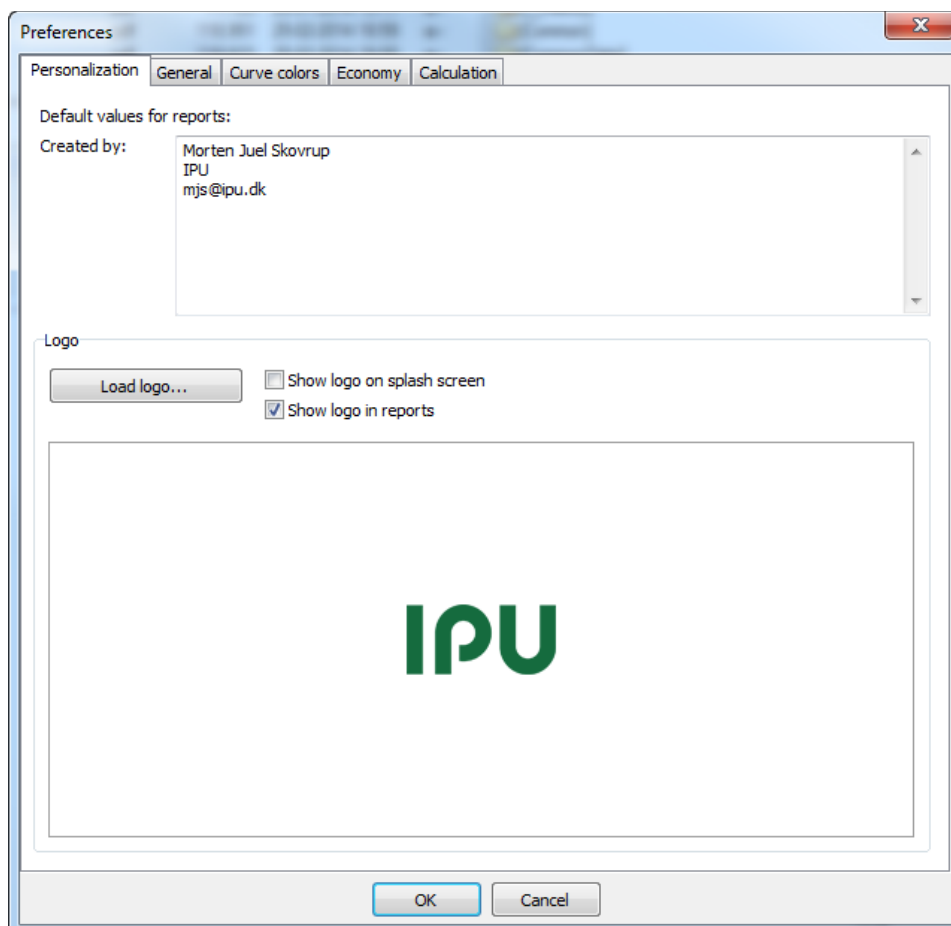
11 Options, preferences and units

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.'

11.1 Preferences

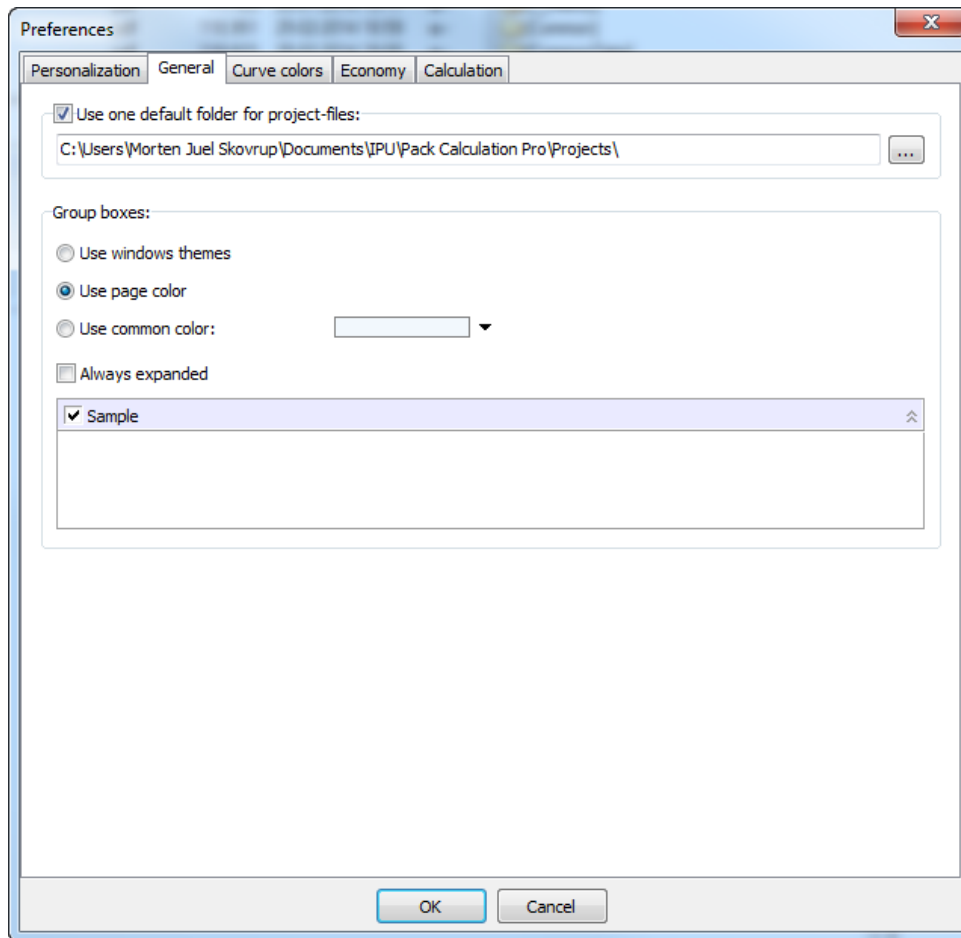
When you select the Options|Preferences menu you will see the following dialog:



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

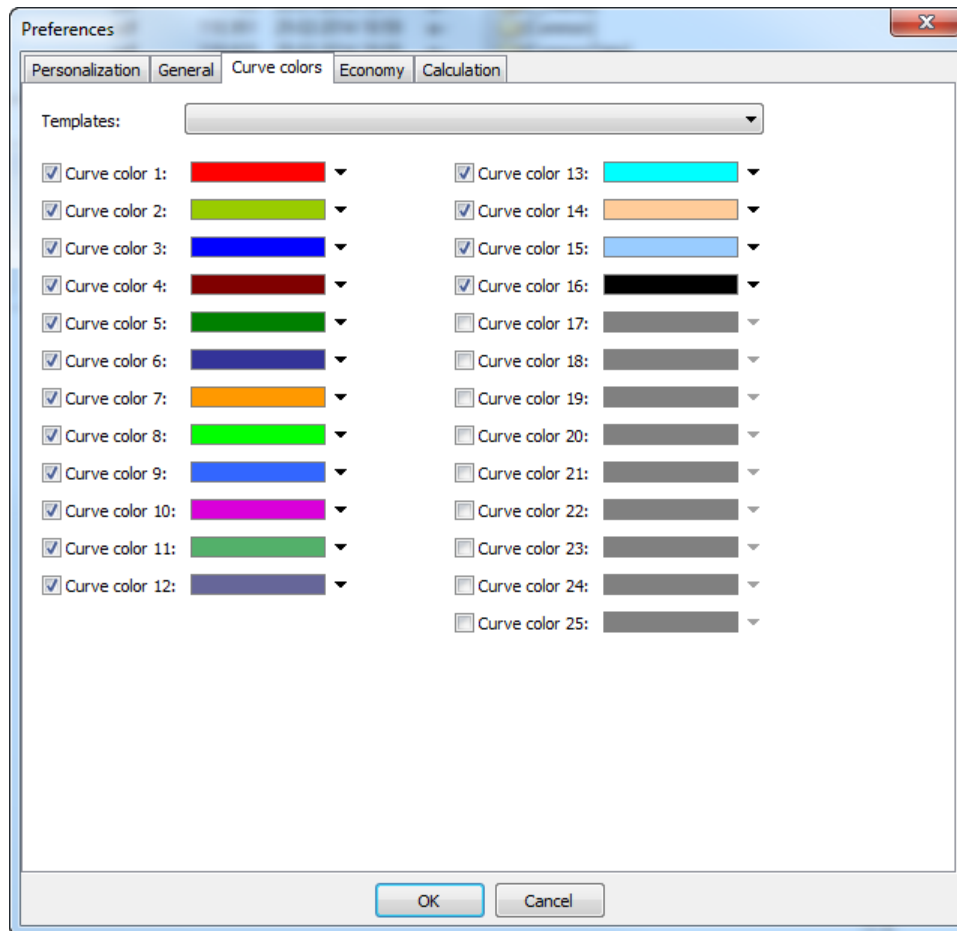
11.1.1 General

The general page looks like this:



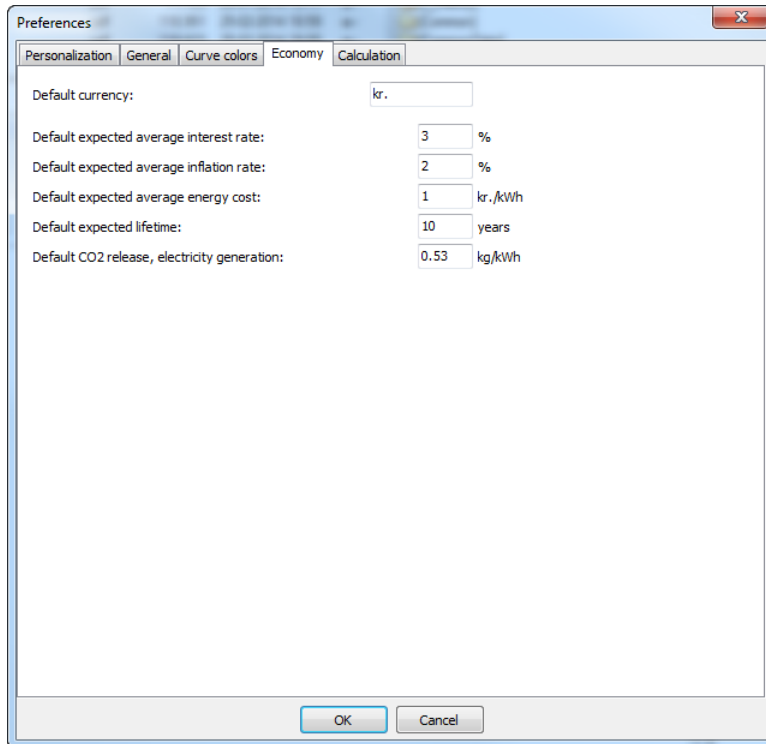
Here you can specify the default location on your projects, and what the different elements in Pack Calculation Pro shall look like – try changing the options and see the effect on the pages where your system is defined.

11.1.2 Curve colors



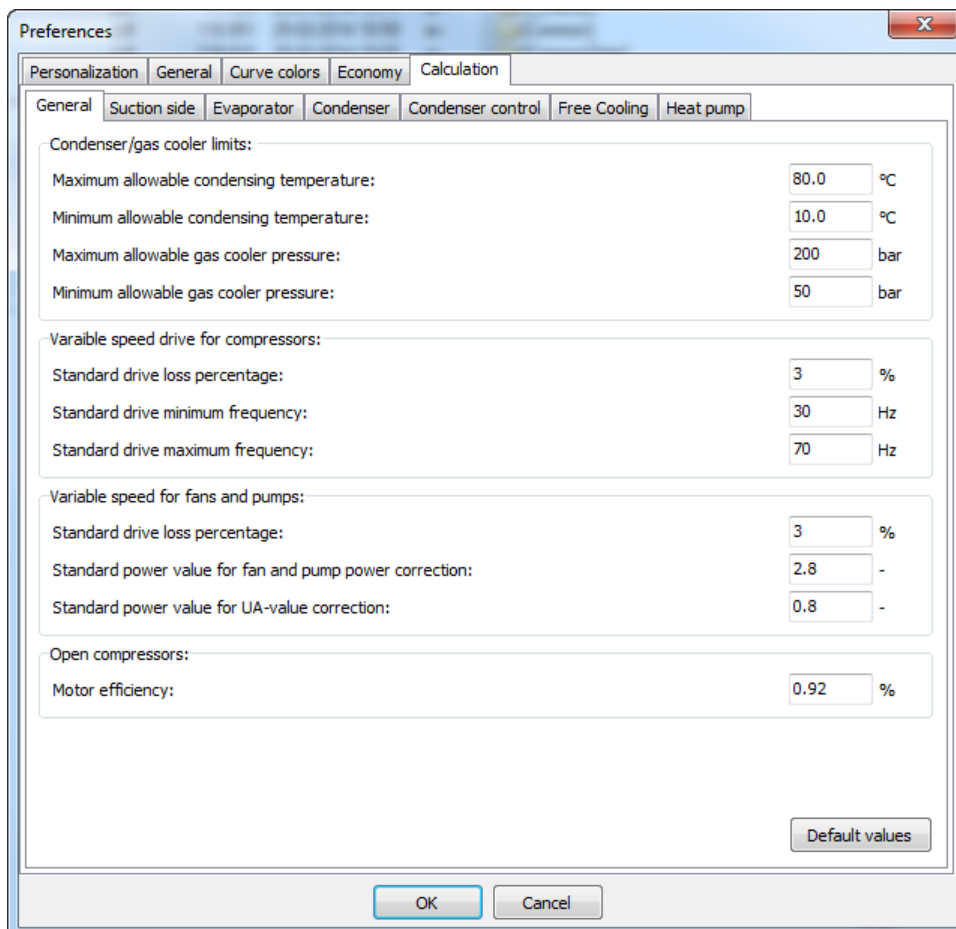
On the curve colors page you can select the colors of the curves on the plot shown on the Calculate|Plots page. There are a number of templates you can select between, but you can also define your own colors. The first curves curve on the plot get curve color 1, the second color 2 etc. The colors starts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

11.1.3 Economy



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

11.1.4 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.

11.2 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 [m³]
- Area: Square meters [m²]
- Mass flow: Kilogram per hour [kg/h]
- Volume flow: Cubic meter per hour [m³/h]

Additional options:

- Power supply: 50 Hz, 60 Hz
- Coefficient of performance: Use COP, Use EER

Buttons on the right: European, American, SI. Buttons at the bottom: OK, Cancel.

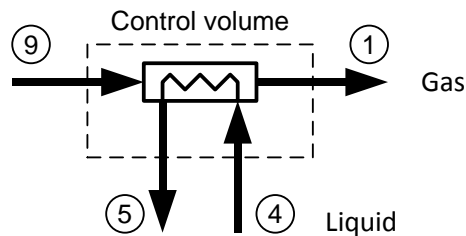
Besides selecting units you also select which power supply frequency should be the default (will effect selecting compressors from the database) and whether you prefer COP or EER for the coefficient of performance.

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 have to calculate again.

A Heat exchanger efficiency

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

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

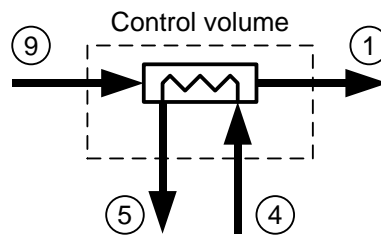


The maximum heat that can be transferred to the gas, is equal to the case where the gas is heated to the temperature T_4 :

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

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 :

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

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
ΔP	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
ΔT	Is a temperature difference (temperature is the driving potential)
σ	Is a combined heat and mass transfer coefficient
ΔI	Is an enthalpy difference (humid air)

ΔT 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 ΔI 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 ΔI is chosen as:

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

Where:

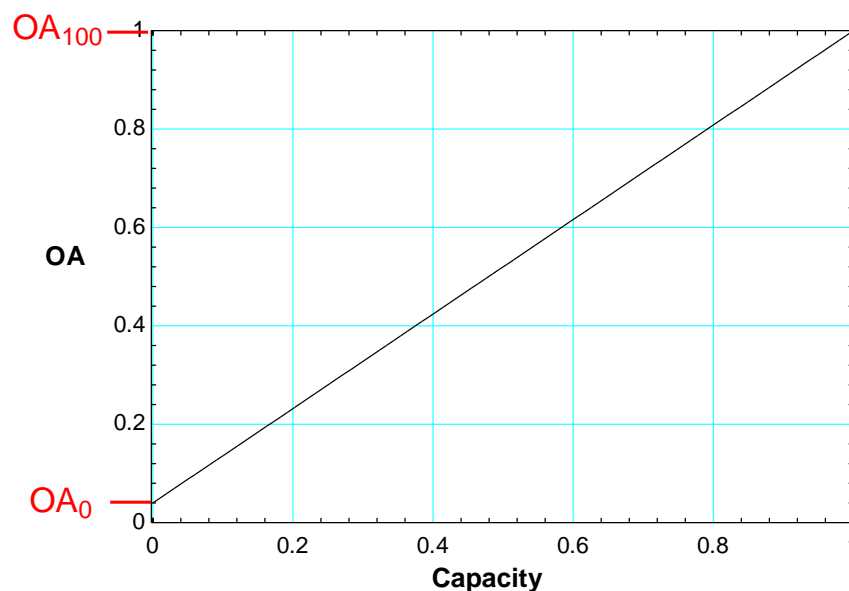
I_c is the saturated enthalpy of humid air taken at the condensation temperature.

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 σ is a function of temperature or humidity.

This means that if you know U (or σ) 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 σ), and from the capacity you can calculate the power consumption of the fans (and/or pumps).

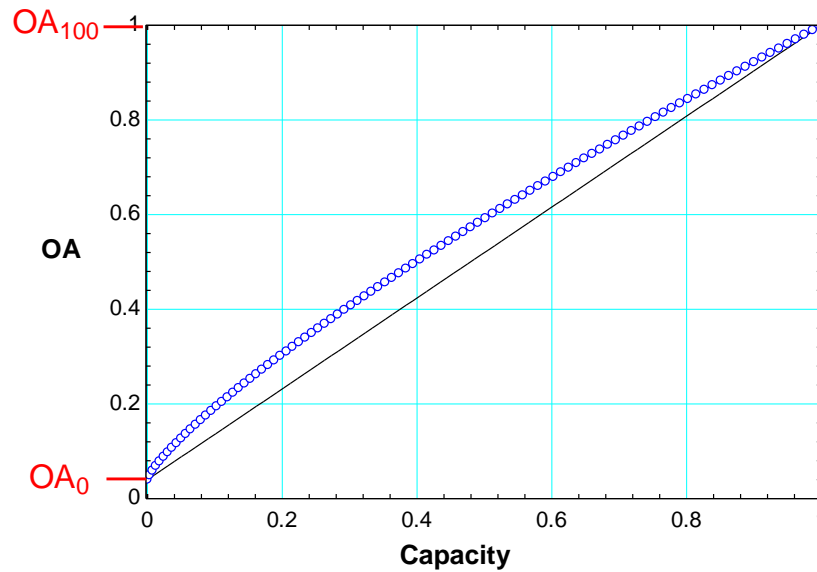
Even though the capacity of the equipment is 0 (fans and pumps turned off) a condenser will typically have some condenser capacity. In case of an air cooled condenser for example, air will still flow through the condenser by natural convection even though the fans are turned off.

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:

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

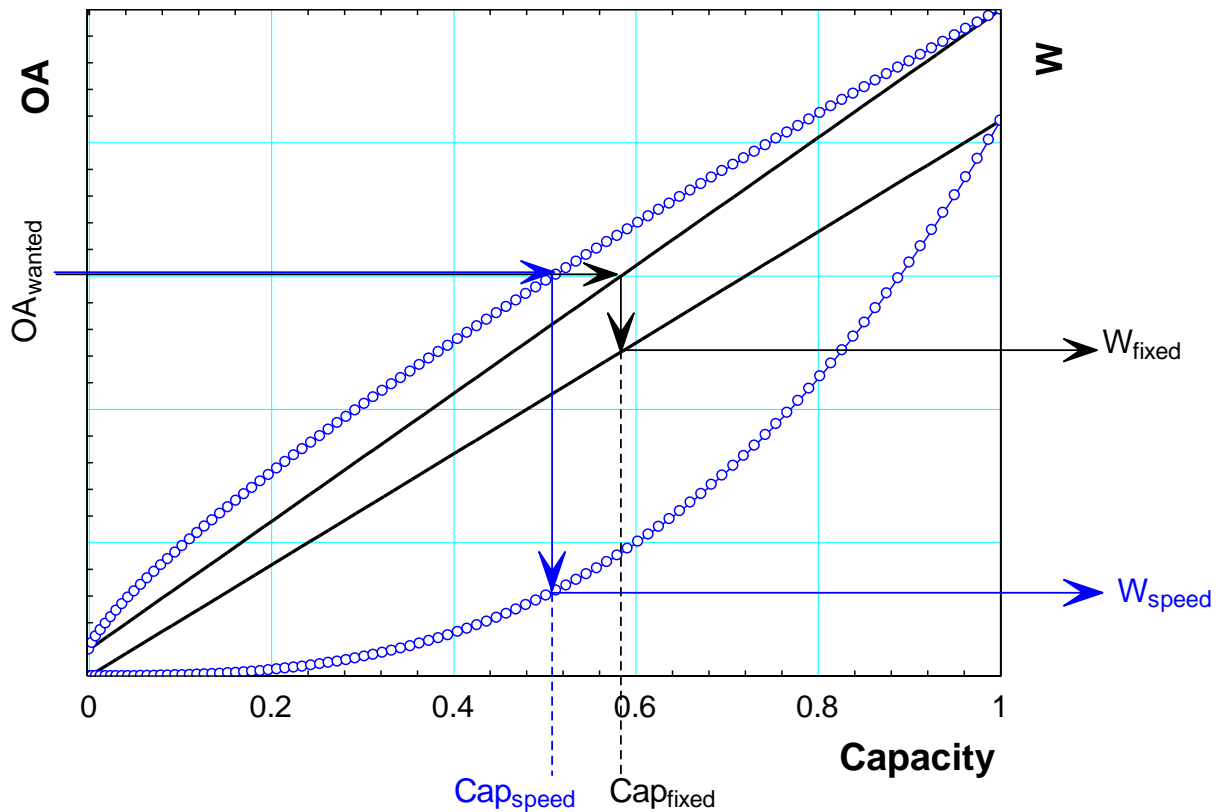
Where $n = 0.8$ if the equipment is speed controlled else $n = 1$.

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 $m = 1$.

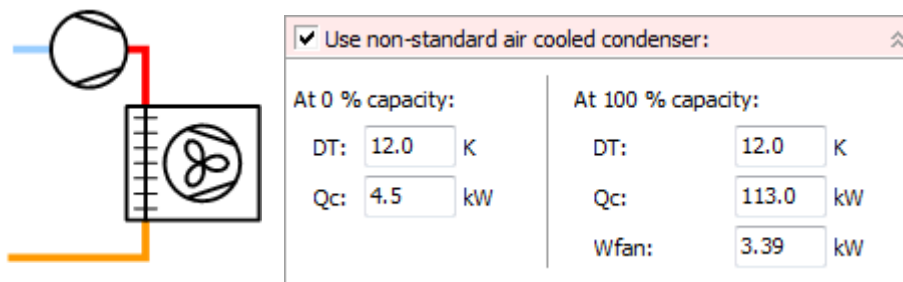
The procedure is illustrated below:



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.

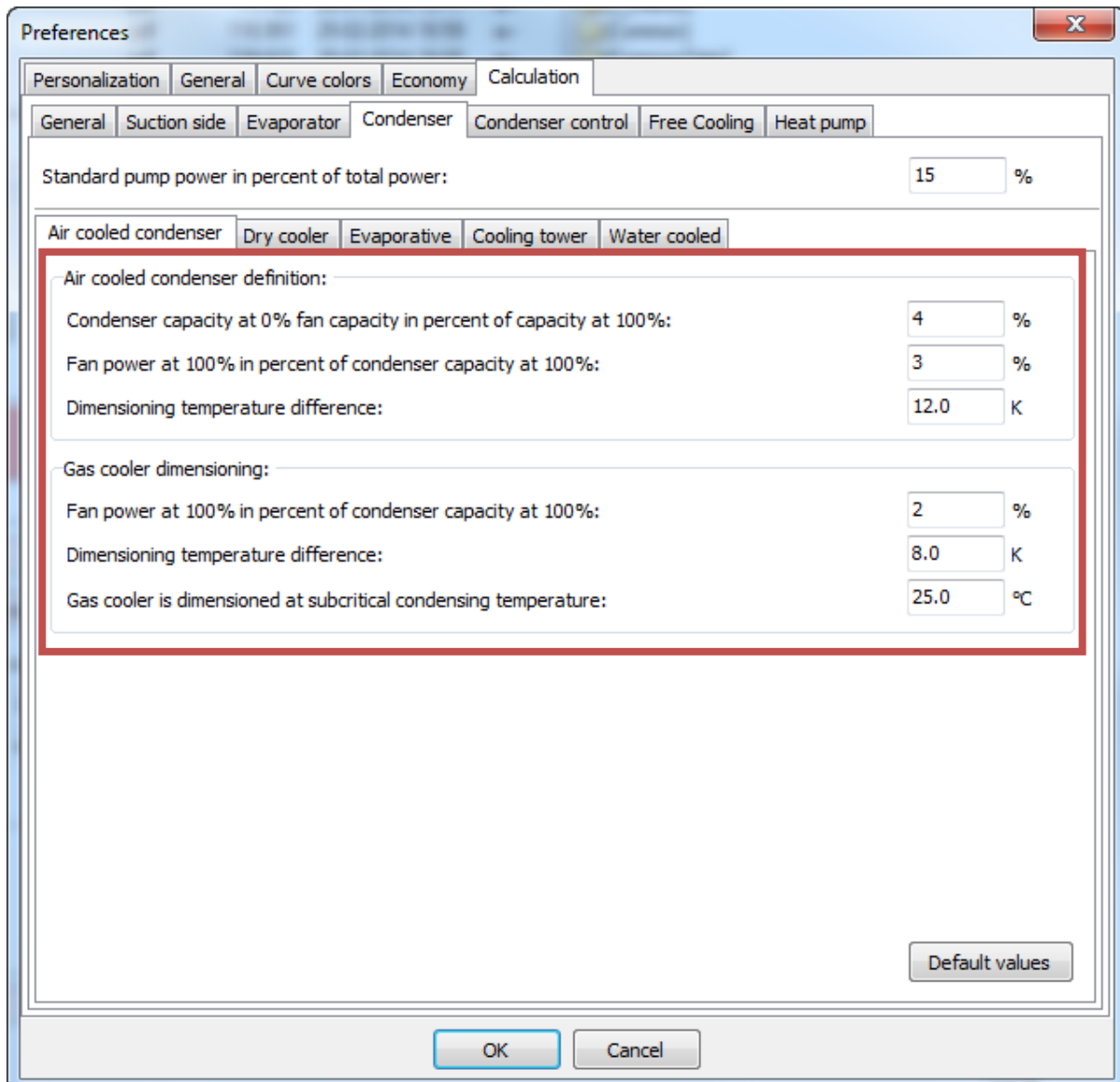
At 0% capacity:

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

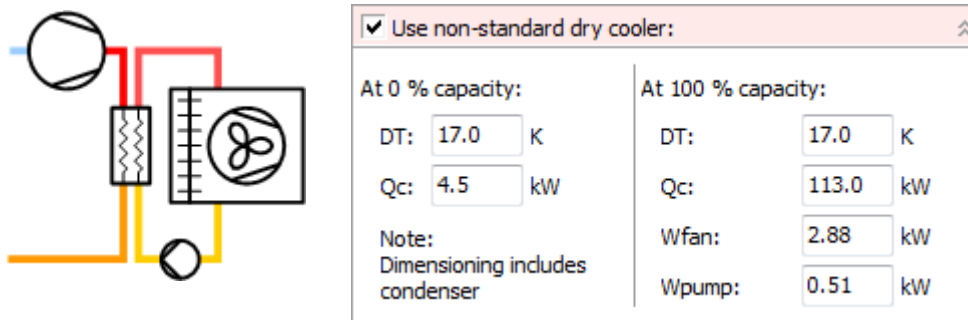
If you instead have a transcritical system, the settings are the same (the gas cooler is dimensioned as a condenser), except that the default values are different:

- **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



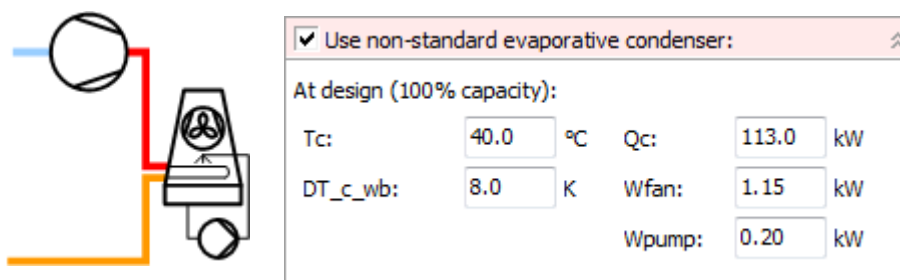
The settings for a dry cooler are the same as for an air cooled condenser, except that the default values are different:

Dry 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

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:

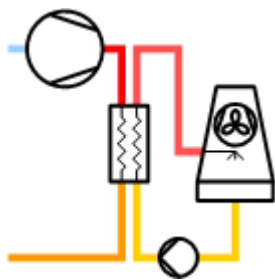
Evaporative condenser definition:

Fan and pump power at 100% in percent of condenser capacity at 100%:	<input type="text" value="1.2"/>	%
Dimensioning temperature difference, wet bulb to condensing:	<input type="text" value="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:	<input type="text" value="40.0"/>	°C	Qc: <input type="text" value="113.0"/> kW
DT_c_wb:	<input type="text" value="15.0"/>	K	Wfan: <input type="text" value="1.44"/> kW
Liquid/gas ratio:	<input type="text" value="2.0"/>	-	Wpump: <input type="text" value="0.25"/> kW

The settings for the cooling tower 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.
- **Liquid/gas ratio.** Ratio of water/air flow

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

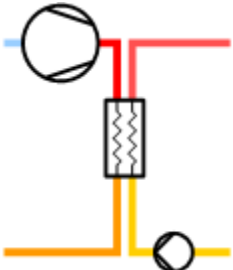
Cooling tower definition:

Fan and pump power at 100% in percent of condenser capacity at 100%:	<input type="text" value="1.5"/>	%
Dimensioning Liquid/gas ratio:	<input type="text" value="2"/>	-
Dimensioning approach, condensing temperature - water in:	<input type="text" value="2.0"/>	K
Dimensioning water temperature increase in condenser:	<input type="text" value="5.0"/>	K
Dimensioning DT, condensing - wet bulb:	<input type="text" value="15.0"/>	K
Dimensioning filling constant:	<input type="text" value="-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.

B.5 Water cooled

The model of the water cooled condenser can be seen as an 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 both define the condenser ambient temperature (water temperature) either as a profile or just a constant.

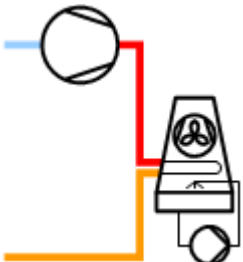
The size of the condenser is as for the rest of the condenser models. The default values can be changed in the Options|Preferences menu and are:

Water cooled condenser definition:

Pump power at 100% in percent of condenser capacity at 100%: 3 %

B.6 Hybrid cooler

The hybrid cooler is essentially an air cooled condenser, where you – on hot days – try to saturate the air entering the condenser with water. The hybrid cooler model is experimental at the moment 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 ³ /h		

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

- Efficiency which is a measure of how well the water system is able to saturate the air. It is calculated as:

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

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

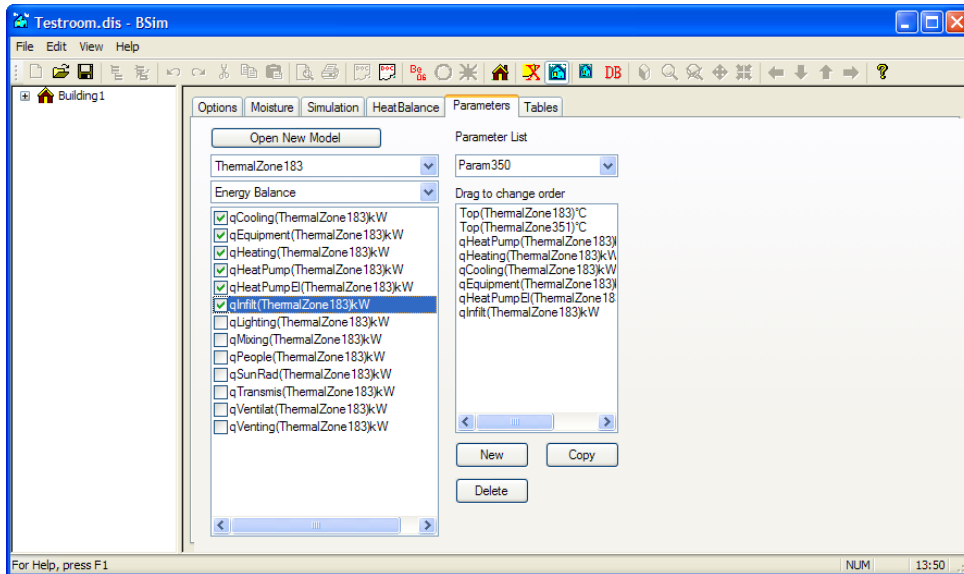
$T_{cond,amb}$ is the “ambient” temperature used when calculating the condenser. So when the efficiency is 0, then $T_{cond,amb}$ is equal to the dry temperature (air cooled condenser) and when the efficiency is 1, $T_{cond,amb}$ is equal to the wet bulb temperature (evaporative condenser).

- Tamb_min which is the minimum (dry) ambient temperature where water is used on the cooler (i.e. the hybrid cooler works as an air cooled condenser in winter time).
- Vair, which is the air volume flow, enabling the program to calculate the water consumption.

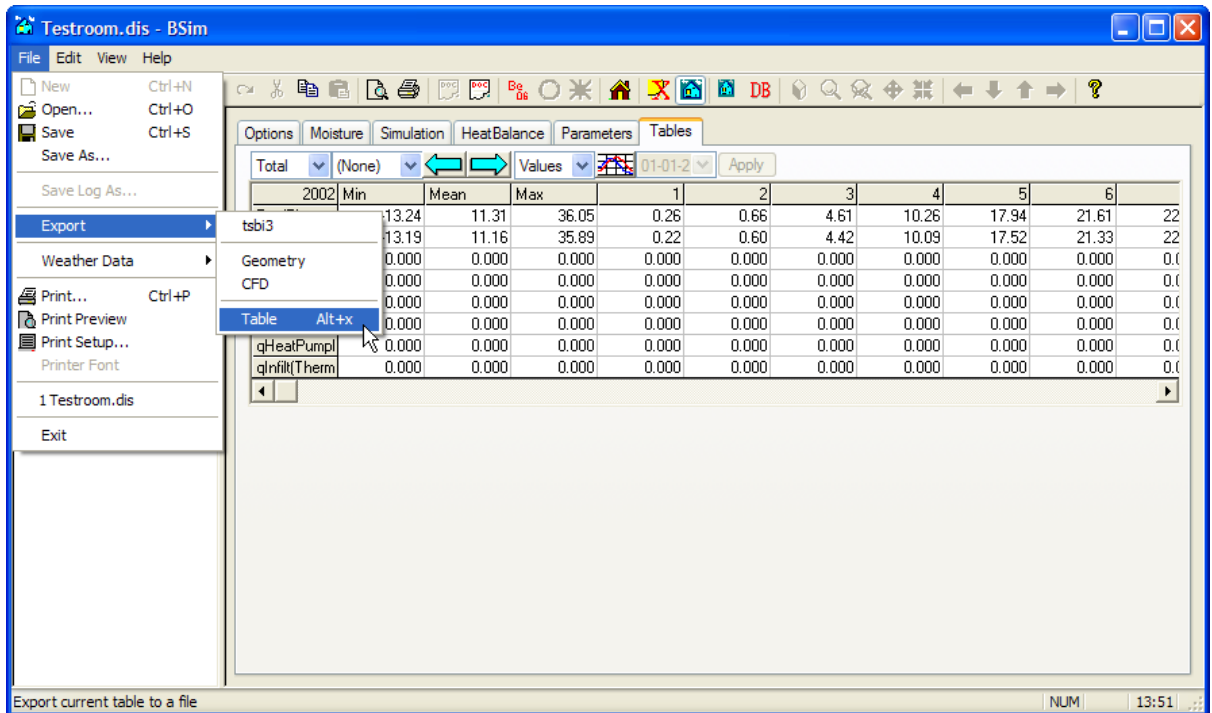
C Integration with BSim

In BSim you export the data by:

- 1) Add relevant parameters to your simulation results:

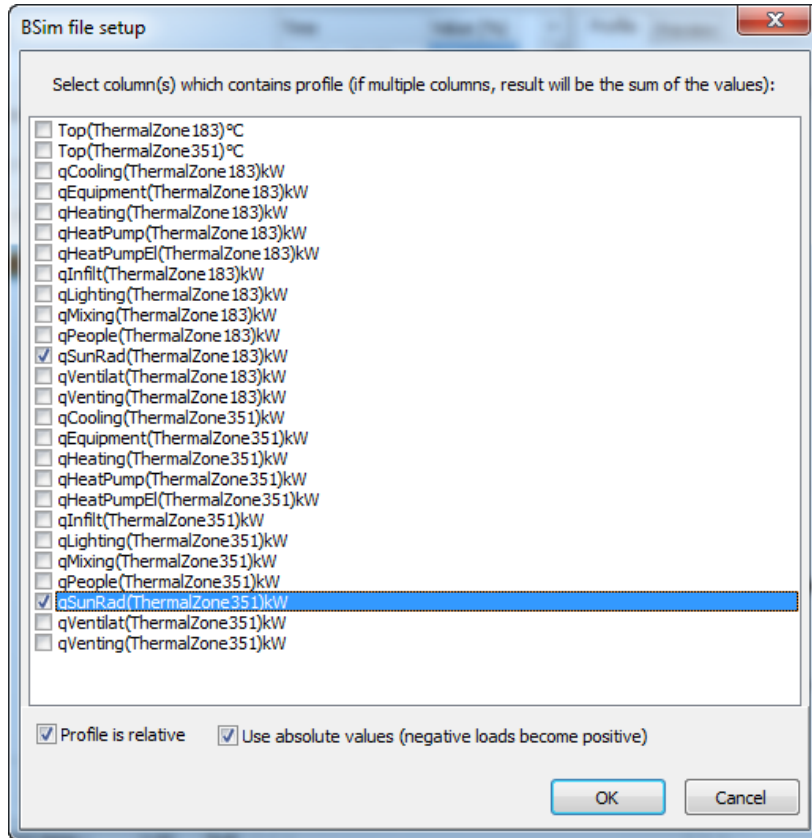


- 2) Run the simulation for one year
- 3) Go to the Tables tab, and export the table:

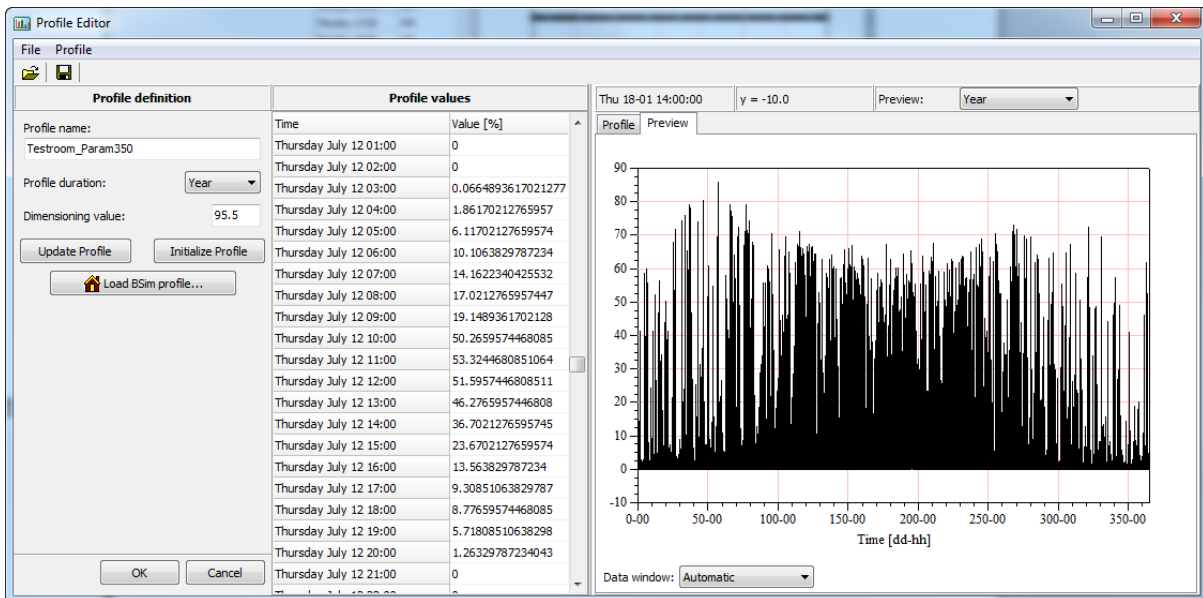


The file you generate can be loaded directly into PackCalc.

When you open the file from the Profile editor (see chapter 6.1.1), 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:



D Rules of thumb for raising temperatures

When you run simulations with constant evaporation temperature (see also 6.1.5), then it can be very difficult proving energy savings using variable speed compressors and fans. Experience show though, that if you have variable speed control then operation is much more smooth and depending on whether you use electronic or thermostatic expansion valves, you are able to 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)

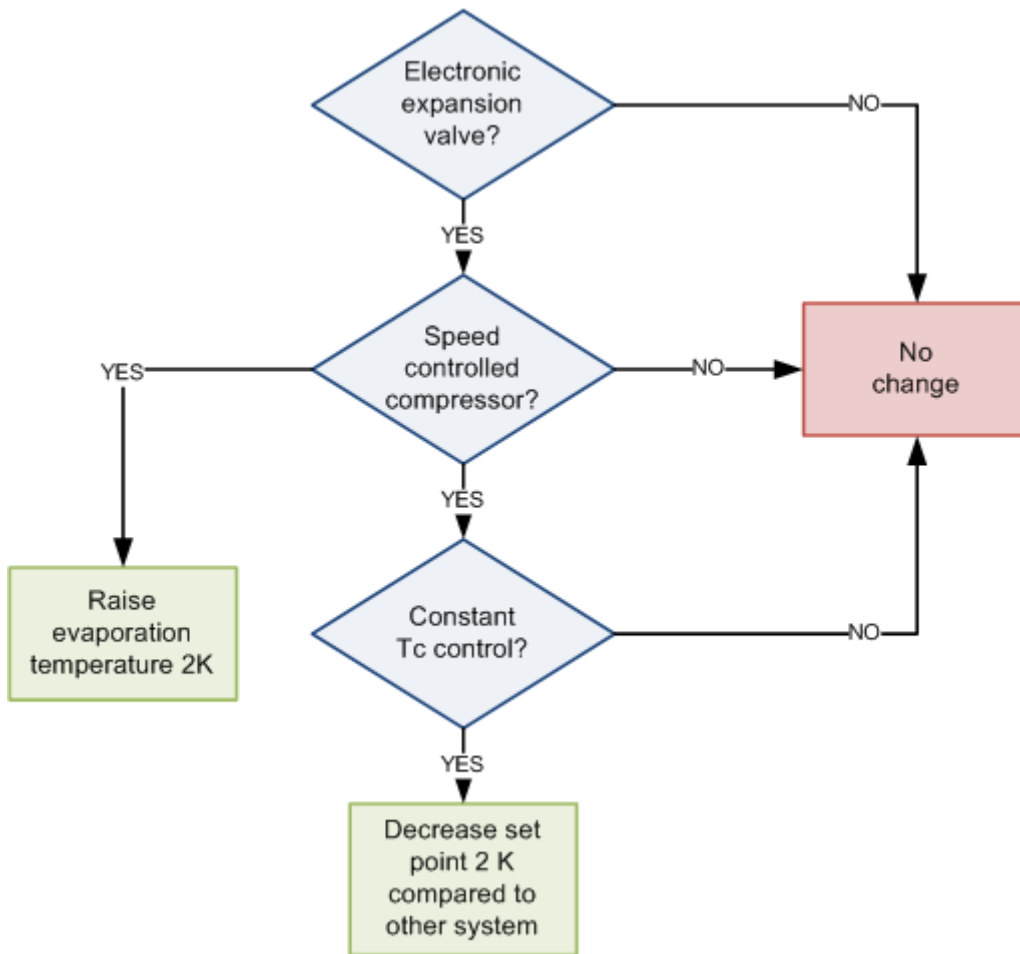
If you control the condenser capacity so that the condensation temperature to follow the ambient temperature, then you should change the *minimum condensation temperature* according to whether you use variable speed fans, but also according to your expansion valve type:

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 CO₂, 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)

