DEA & EESD

Energy Partnership Programme between Viet Nam and Denmark

Catalogue for industrial cooling systems

Final

2. July 2024

Viegand Maagøe

AIM AND CONTENTS OF CATALOGUE

This catalogue serves two main purposes.

- The first is to give insights into how cooling systems can be optimized to run more energy efficiently. This concerns both the chiller itself but also the system, where end use is in focus. This part of the catalogue is aimed at technical heads of operation but also people who must perform energy audits.
- The second part of the catalogue concerns the sourcing of new cooling equipment; what should be considered when buying new equipment and the procurement process. This part of the catalogue is aimed at people in charge of sourcing new cooling equipment.

The catalogue has the following contents:

- Section 1: Improving energy efficiency of industrial cooling systems
- Section 2: Selection and equipment of a new cooling installations
- Section 3. Procurement of new cooling installations

In annexes of the catalogue, more detailed information can be found:

- Annex 1: Selected national and international suppliers of cooling systems

The catalogue further describes several cases for rehabilitating cooling installations as well as the business case for replacing old systems with new high efficient designs.

Scope of users

This catalogue is relevant for all industrial cooling systems in Vietnam. By industrial cooling there is a focus on process consumers and refrigeration, but the large-scale air condition can also find inspiration. There is not an aim on specific cooling technologies or refrigerant. But since ammonia as a refrigerant is dominating the industrial cooling sector in Vietnam, small part of the catalogue is only relevant for this.

Content

1 Improving energy efficiency of industrial cooling systems

Electricity consumption for cooling/refrigeration can make up a very large part of the energy consumption at factories. For example, it accounts for up to 75% of the electricity consumption in the Vietnamese sea food sector. This makes it a technical area of great interest and importance in the study of energy saving potentials.

1.1 Fundamentals of industrial cooling systems

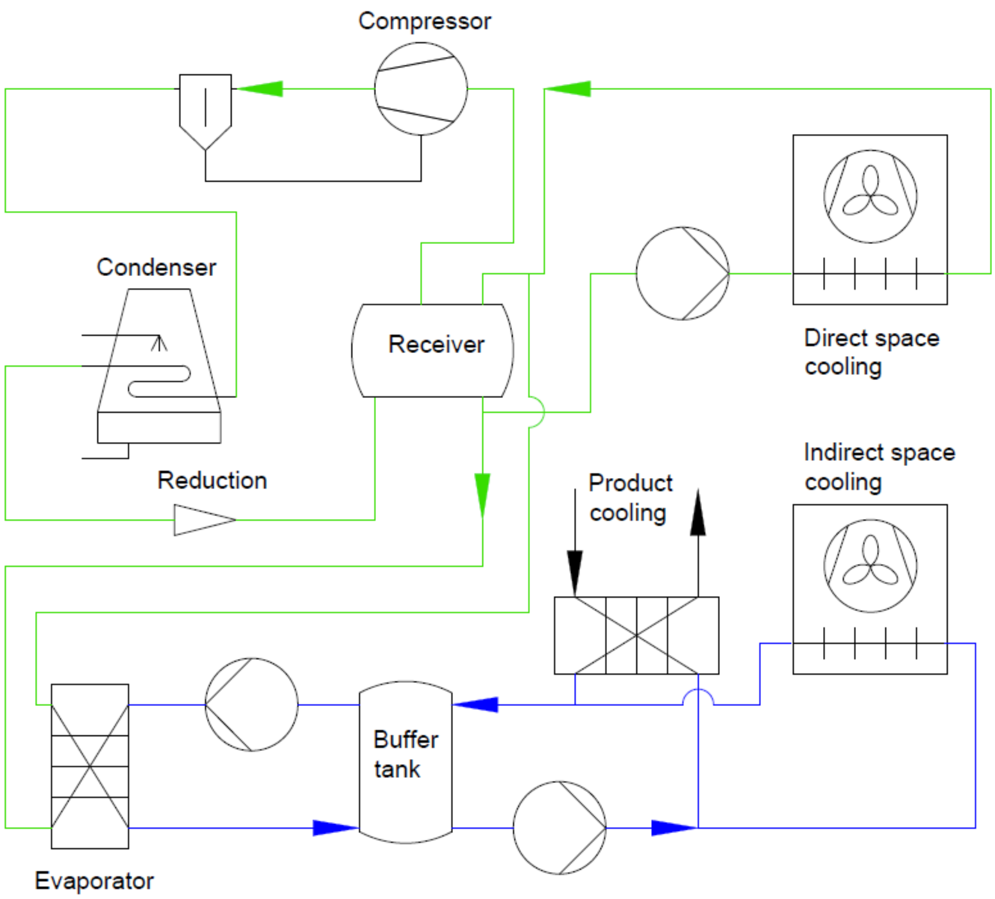

Figure 1. Generic cooling system.c

On Figure 1 a cooling system is illustrated with the main components/areas, that will always be present in a cooling system:

- Compressor
- Condenser
- Evaporators
- Pumps
- Distribution system

Cooling systems can be designed in many ways depending on the specific applications. In Figure 1 a system is shown where the cooling is supplied directly by the refrigerant 'Direct space cooling' and indirectly via a secondary circuit for 'Product cooling' and 'Indirect space cooling'.

1.2 Improvements to overall system efficiency

In this section, considerations for the overall energy optimization of the system are presented. Apart from the things mentioned in this section, it should also be considered that replacing old run-down equipment could lead to significant savings.

1.2.1 Split of cooling supply

Cooling capacity is an expensive resource, and the lower the temperature, the more expensive it gets. As a rule of thumb for each degree the evaporating temperature is lowered the electrical consumption increases with 3-4%. It is therefore of major importance that the refrigeration plant delivers cooling at correct temperature, and not lower than necessary.

If there are cooling demands at different temperatures, they should be provided with cooling capacity from different pressure levels to avoid expensive and inefficient use of compressors. This will normally require installation of new pipes. This is illustrated in Figure 12, a cascade system, with an intermediate evaporator and further elaborated on in section 2.3.1.1.

A typical situation is that air conditioning in production areas (above 0 ºC) is supplied with cooling capacity from the same plant as cold stores (below -18 ºC).

The two main reasons for this situation are:

- The cooling demand has changed since the construction of the facility. Either the production has expanded or changed.
- The design of the refrigeration plant has been poorly made from the beginning.

The saving potential can be between 10-50% of total electricity used by the compressors, of that share of cooling delivered to the units operated at a too low temperature.
The situation and solution opportunities vary greatly from refrigeration plant to refrigeration plant.

Diagnosis of situation:

The process to determine if there is an energy saving potential or not can take some time, but it is easy to perform.

- Check the temperatures at the suction side of the compressors (based on readings of the suction pressure)
- Determine which compressors that provide cooling for which users.
- Check the temperatures needed at each of the cooling consumers (the temperature that product is cooled down to)
    - If the differences in temperatures between compressor “suction temperature” and consumer temperature are larger than 4 K, there is potential for improvement.

Alternatively contact a specialist to get help with the above. If it is possible to reconfigure some of the refrigeration system, a supplier should help with this work.

CASE

Two industrial flake ice machines with capacity of 15 ton/day and 20 ton/day are put into operation at workshop 2. The inlet water has temperature at 30°C (normal water). The COP of flake ice system (2.18 kW_{hermel}/kW_{elec}) is naturally lower than the COP of refrigeration system which is also located at the factory (3 $kW_{thermal}/kW_{elec}$).

The factory changed the feed water to the flake ice machines to use cold water from the refrigeration system in workshop 1 to supply directly. Cold water output from the refrigeration system of workshop 1 has a lower temperature of about 7°C - 8°C which helps save electricity. The overall saving arises from precooling of water with a system with a higher COP. Another benefit is that the flake ice production time is faster, and the capacity is increased as well.

- Electricity saving 30,664 kWh/year
- Annual cost savings of 52 million VND/year
- Reduce GHG emissions by 25.9 tons of CO_2/year
- Payback time 1.4 years.

1.2.2 Use of free cooling

If some cooling process requires cooling water at relatively high temperatures (for example injection molding machines) it can be considered if the cooling can be supplied by wet or dry free cooling towers.

This requires that the ambient conditions are sufficiently cold for the cooling water to be produced. As a rule of thumb wet cooling towers can produce cooling water 5 ºC over the wet bulb temperature and dry cooling towers can produce cooling water 10 ºC over the dry bulb temperature.

If free cooling can be implemented it can lead to significant energy savings, as free cooling towers can run with COPs around 20-40. If the free cooling tower is not capable of delivering all the cooling, it can be considered to combine the free cooling tower and chiller in the system and let the free cooling tower produce cooling when the ambient conditions allow it.

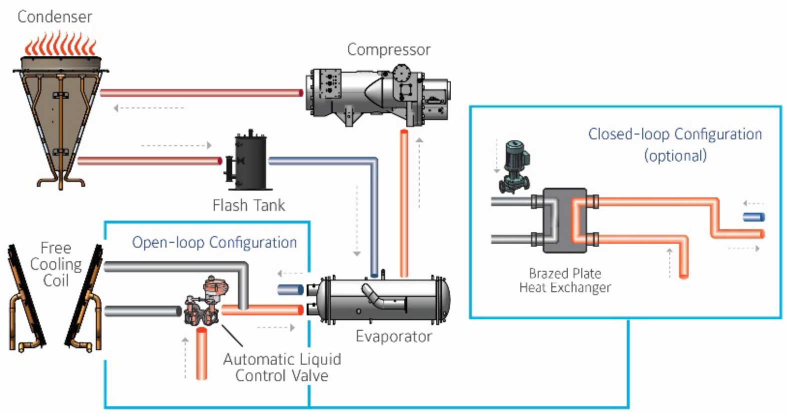

Figure 2. A cooling system that can switch between free cooling and mechanical mode depending on ambient conditions [1].

Diagnosis of situation:
The following steps be followed.

- Find out what the minimum required cooling temperature and check if it can be increased (see section 1.6.3)
- Check the dry bulb and the wet bulb temperatures in the region throughout the year (such as month by month) at which the site is located.
- If the wet bulb temperature is more than 5 ºC below the required temperature at least 30% of the year, an assessment of passive cooling should be made.
    - If the above is the case, contact expert/supplier or perform more detailed calculations yourself.

1.2.3 Install VSD on evaporator, cooling tower and dry cooler fans

In most cooling systems the load varies considerably during the day and the year, following changes in outdoor temperature, sunshine, amount of product to be cooled etc. If there is no control of the fan speed on the evaporators, cooling towers or dry coolers, the electrical consumption on the motors will be higher than necessary without any positive effects. The need for fan operation can easily be 50% of full-load operation or even less while the motor is running 100%.

Installing VSD on fan motors can be relevant for all types of air coolers and cooling towers, and the energy saving can be up to 40% of the electricity used per unit.

Alternatively, the operation of fans can be sequenced and controlled automatically - or even manually if long periods at low cooling loads occur.

The saving potential will vary widely from setup to setup. It first depends on the load pattern of the cooling tower or the dry cooler. The more part load operation, the higher potential, and it is advised to ask an expert to calculate the exact saving potential. Two general situations are described below.

- Units with one fan, or more fans controlled similar, the potential will normally be between 5-25%.
- Units with multiple fans controlled individually, the potential will normally be between 2-15%.

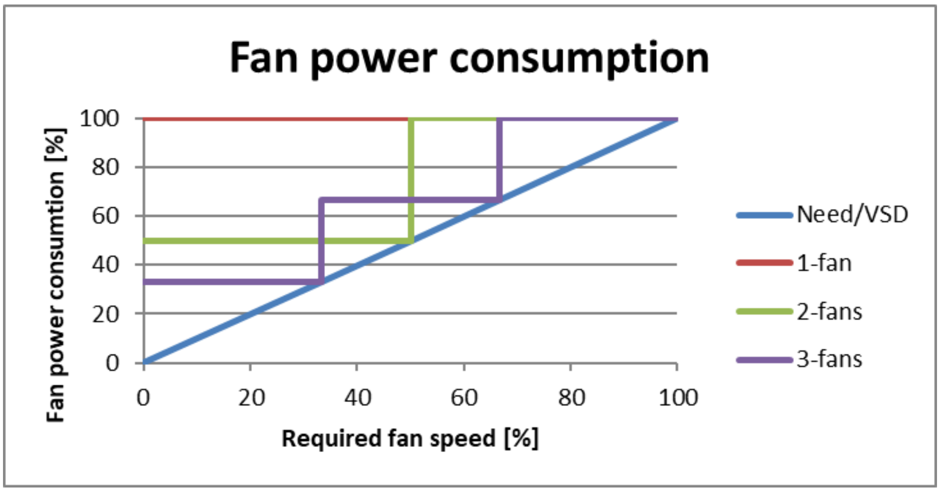

Figure 3. Actual fan power consumption vs. the ideally required fan speed.

Diagnosis of situation:
In this case it is easy to determine if there are any energy saving potentials. If there are not installed a VSD module on the fans, there is a potential. It is necessary to contact an expert to calculate the specific potential and help finding a suitable solution.

CASE

Company name: MINH DANG Co., Ltd	
Address: 83 Provincial Road 8, My Xuyen Town, My Xuyen District, Soc Trang Province	
Project Summary: Replacement of piston refrigeration compressors with screw refrigeration compressors. The project targets to reduce the energy costs and the emission of greenhouse gases.	
Year of implementation: 2017	
Status before implementation	**Result**
Minh Dang Co., Ltd. produces frozen seafood for export with main products including: squid, octopus. The factory has 2 continuous refrigeration systems for cold storage, IQF conveyor, and re-freezing. In order to save the energy, the plant was planning to replace 4 existing reciprocating compressors with 2 high-efficient screw refrigeration compressors.	The plant has replaced 4 reciprocating refrigeration compressors with 2 high-efficient screw compressors. Total power consumption for the refrigeration systems reduced by 30.6% 298 tons of CO_2/ year have been be reduced.

Existing reciprocating compressors

Screw refrigeration compressors for cold storage, freezers

Screw refrigeration compressor for (IQF) conveyor, re-freezing

Result of the project:	
Total investment costs:	VND 3,269 Million
Power saving:	450,387 kWh/ year.
Cost savings:	VND 691 Million
Payback time:	4.7 years

1.2.4 Install and maintain an air purger

The efficiency and capacity of a refrigeration plant can be impaired significantly if there is air in the refrigerant system. Even if there already are installed an air purger in the system, there can still be large quantities of air.

If air is present in the system, it will take up space in the condenser, minimizing the effective surface area. It can also block drainage systems, resulting in problems with high pressure float valves and catalyse corrosion reactions. It is not enough just to have an air purger - it should be an effective and properly designed one.

The energy saving potential will normally be from 3 to 9 % of the electricity used by the compressors. The saving will be generated by lowering the condensation temperature. For each degree it is lowered, the energy efficiency will increase by 3-4 %.

Another important benefit is that the capacity is increased by approximately 1 % for each degree the condensation temperature is lowered.

Diagnosis of situation:

Air in the system can cause different problems that all indicate that air is present. If some of the following symptoms are present, most likely there is air in the system.

- The refrigeration plant has lost capacity over the years.

- There are capacity problems during the hot summer periods.
- The oil is decomposing.

If there is no purger, one should be installed. Contact a supplier or specialist in high efficiency air purgers and get help with the installation. If there is one it should regularly be maintained.

CASE

During operation, non-condensable gas (air) enters the refrigeration system and affects the refrigerant R717 (NH_3), increasing the condensing pressure of the refrigeration system, thereby increasing the condensation temperature. This leads to increased power consumption and lower efficiency, while also causing damage to the piping system.

Factory installed Purging System to remove non-condensable gas from the NH_3 refrigerant.

- Reduce electricity consumption by 10.8% or save 207,732 kWh/year
- Annual cost savings of 360 million VND
- Reduce GHG emissions by 167 tons of CO_2/year
- 1.4 years payback time

1.2.5 Install and maintain a water purger

Water in the refrigerant is a common problem on many refrigeration plants and it is often not recognized by the operating personnel.

For each percentage of water in the refrigerant, the capacity falls by 2 % and the power consumption increases with 1 %. Beside this, the oil breaks down; gaskets can start leaking, tears on valves can occur and sludge in the system will build up.

The solution is to have an effective water purger installed in the system that removes water from the refrigerant. The water content should never be higher than 1 %.

The energy saving potential varies according to the water content of the refrigerant which varies according to the general maintenance of the refrigeration plant. In a typical case the energy saving will be 6 to 9 % of the electricity used by the compressors. The saving potential can sometimes be even higher.

Diagnosis of situation:
There are two simple measures to investigate if there is water present in the ammonia:

- Use trained personnel to drain 100 mL of ammonia and put it in a safe place to evaporate. Next step is to measure the remaining liquid in the glass, which will be water. Compare the water content with a table to find the weight percentage. Be sure to drain on the low-pressure side since this is where the water is mostly present.
- If a recirculating evaporator is installed and the operating temperature (as a temperature measurement) is higher than the calculated temperature forms a pressure measurement indicates, there is probably water in the refrigerant. (*Based on a pressure measurement the evaporation temperature is calculated assuming only refrigerant present, hence the partial pressure equals the total pressure. If water is present, the refrigerant partial pressure is lower than the total pressure and hence the evaporating temperature will increase)*

<u>CASE</u>

<table>
<tr><td colspan="2">Company name: MINH DANG CO., LTD</td></tr>
<tr><td colspan="2">Address: 83 Provincial Road 8, My Xuyen Town, My Xuyen District, Soc Trang Province.</td></tr>
<tr><td colspan="2">Project summary: Investment project to renovate the Freezer system, including many solutions. The goal of the project is to reduce energy costs and reduce GHG emissions.</td></tr>
<tr><td colspan="2">Year of implementation: 2018</td></tr>
<tr><td>Status before implementation</td><td>Result</td></tr>
<tr><td>The Freezer system is the largest energy consumption system in the factory. Currently, the factory has 3 Freezer systems operating independently, using NH_3 refrigerant.

Compressor area at the factory
The factory will merge the three currently separate Freezer systems into a new Freezer system.</td><td>The factory has reduced 28.3% of the total power consumption for Freezer system.
</td></tr>
</table>

At the same time, the factory also installed a number of new equipment to improve the energy efficiency of Freezer system, such as: installing non-condensing air separator and water separator from NH_3, installing heat exchangers for cooling water to reduce the amount of flake ice used, installing equipment to automatically adjust the compressor capacity to suit the system's refrigerant load.	Freezer system *after renovation*  *Water separator*

Results of the project:

	- Total investment cost: 5,573 Million VND
	- Energy savings: 959,385 kWh/year
	- Saving cost: 1,588 Million VND
	- Payback: 3.5 years

1.2.6 Size of buffer tank

Some cooling systems are designed with a secondary cooling circuit with a buffer tank, as shown on Figure 1. If this is the case, it is important to make sure that the buffer tank has an appropriate size to optimize how the compressors are running to avoid too many daily start/stops of the compressors. For a system with a buffer tank, more than one start per hour is considered too much.

Furthermore, one should make sure that the buffer tank works appropriately as cooling storage with proper stratification between the cold water and warmer return water. If the two are mixed it will lead to a higher forward temperature in the cooling system than what is delivered from the evaporator.
If for example the forward temperature out of the buffer tank is 2 ºC higher than the what the evaporator delivers, there could be a potential electrical saving of 6-8% by raising the evaporation temperature 2 ºC.

Diagnosis of situation:
Check if the forward temperature from buffer tank is higher than what the evaporator delivers. This can indicate a poor buffer tank design. Contact a local specialist to get an assessment done. Furthermore, check how much time of the year the tank is completely full or empty.

1.2.7 Drop legs on evaporative condenser

Evaporative condensers are usually split in two or more runs on the refrigerant side. It is important for more than one reason that each run with liquid high-pressure refrigerant out of the evaporative condenser has its own individual drop leg with a liquid trap with sufficient high (at least 40 cm of liquid).

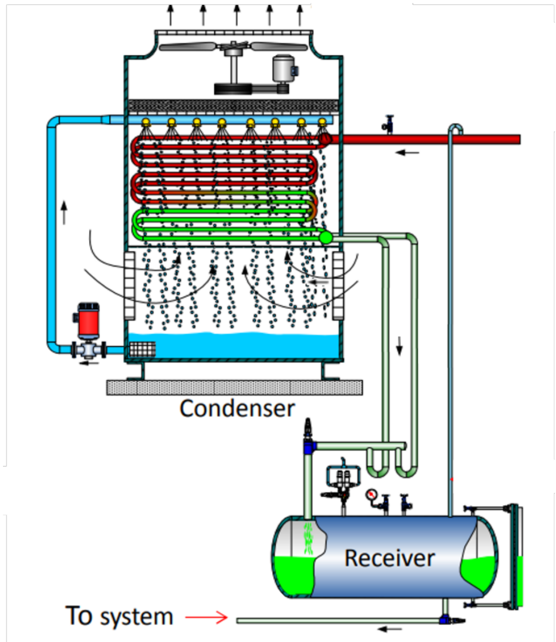

Figure 4. Evaporative condenser and receiver. Note the two individual runs out of the condenser with a drop leg of each off them.

This will firstly ensure an even distribution of refrigerant for each run. Since the runs are connected in both ends, the pressure drops are identical over the runs. If they are not identical in physical geometry, the refrigerant flow, and hence the load, will be different on the runs. In this case, the capacity is not utilized completely, the fans are using too much energy and condensation pressure is too high.

The saving potential is 5-10% of the consumption on the evaporative condenser.

As a secondary thing this will ensure that manual air purging can be done properly. Without this drop leg design, it is not possible.

Diagnosis of situation:
Visually inspect the pipes for individual drop legs with liquid trap and possibility of minimum 40 cm ammonia level.
Normally it is not recommended to change the piping for this reason only, but to be fixed if piping anyhow is changed.

1.2.8 Drop legs on flooded evaporator

The pipe connection from a separator drop leg to the evaporator should be inclined to lead the oil back to the drop leg in a small oil pot. Otherwise, it will end up in the evaporator, usually with no possibility of draining it. It will eventually create fouling in the heat exchanger, decreasing the heat transfer, increasing the pinch point, and increasing the power consumption on the compressor.

Figure 5. Drop leg on flooded evaporator. Red arrow indicates the dropleg [2].

1.3 Compressor

The compressor is the main consumer of electricity in cooling systems. Therefore, it is interesting to look into optimizations of the compressors.

1.3.1 Optimize compressor control system

Inadequate or inappropriate compressor control can lead to high energy losses in the refrigeration plant. This is especially the case for refrigeration plants with multiple compressors and varying cooling demands. The energy efficiency of a compressor (screw compressor) can drop by 30% when it is operating at part load, as illustrated in Figure 5 below.

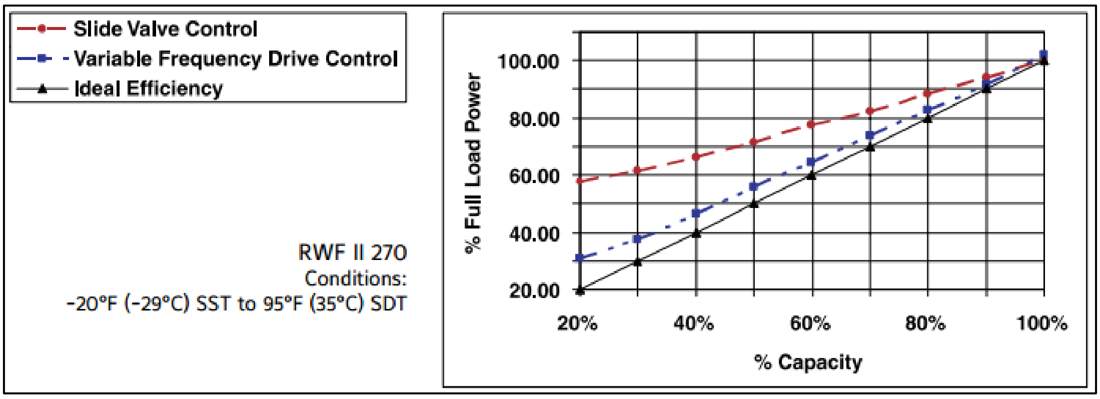

Figure 6. Comparison of power consumption by different regulation methods (screw compressor).

According to Figure 5, power consumption is still relatively high when adjusting capacity to by example 50% when using slide valve control, which can often be avoided when using a proper control system.

A new or updated compressor control system can be relevant under the following circumstances:

- The existing system is old and equipped with old control system.

- The refrigeration plant has changed from its original design (more units),
- Loads or operation patterns have changed.
- VSD has been installed for some of the compressors.
- The refrigeration plant consists of different type and/or sizes of compressors.
- There is no functioning compressor control system.

In a normal plant in the Vietnam, the energy saving potential is at least 5% of the electricity used for refrigeration. But the energy saving is very dependent on the existing refrigeration plant and the actual saving potential must be calculated by an expert. It can vary from a few percent and up to 20% in the best cases.

Investment costs of installing a new control system will often be relatively high thus leading to long payback periods. However, if a control system is installed along with other measures also to increase cooling capacity, payback period can be relatively short.

Diagnosis of situation:
To detect if there is an energy saving potential, an expert must be consulted. If one or more of the following points fits on your refrigeration plant, there is basis to invite an expert:
- More than one compressor is installed in the same refrigeration system.
- Compressors are controlled by on/off or manual regulation.
- Screw compressors are operated in part load.
- Fixed suction and/or discharge pressure is used.

Reciprocating compressors are usually more efficient at part-load operation, but also here a proper control system will be advantageous.

Produce cooling when electricity prices are low
In the control system it is possible to set different set points for temperatures and operating conditions. This can be used to run the compressors as little as possible when electric tariffs are high and as much as possible when they are low. This will not save energy at the facility, but the operational cost will be lower.

CASE

<table>
<tr><td colspan="2">Company name: MINH DANG Co., Ltd</td></tr>
<tr><td colspan="2">Address: 83 Provincial Road 8, My Xuyen Town, My Xuyen District, Soc Trang Province</td></tr>
<tr><td colspan="2">Project Summary: Replacement of piston refrigeration compressors with screw refrigeration compressors. The project targets to reduce the energy costs and the emission of greenhouse gases.</td></tr>
<tr><td colspan="2">Year of implementation: 2017</td></tr>
<tr><td>Status before implementation

Minh Dang Co., Ltd. produces frozen seafood for export with main products including: squid, octopus. The factory has 2 continuous refrigeration systems for cold storage, IQF conveyor, and re-freezing.

In order to save the energy, the plant was planning to replace 4 existing reciprocating compressors with 2 high-efficient screw refrigeration compressors.</td><td>Result

The plant has replaced 4 reciprocating refrigeration compressors with 2 high-efficient screw compressors. Total power consumption for the refrigeration systems reduced by 30.6% 298 tons of CO2/ year have been be reduced.</td></tr>
</table>

 *Existing reciprocating compressors*	 *Screw refrigeration compressors for cold storage, freezers*  *Screw refrigeration compressor for (IQF) conveyor, re-freezing*
Result of the project:	
Total investment costs:	VND 3,269 Million
Power saving:	450,387 kWh/ year.
Cost savings:	VND 691 Million
Payback time:	4.7 years

1.3.2 Use two stage compression

When a compressor operates with high pressure difference from suction to discharge side, energy efficiency drops. The higher the pressure difference is, the lower efficiency and capacity the compressor has.

The compressor is the single largest energy consumer in the refrigeration plant, so the potential for saving is very high. If the pressure difference is high, the compression should take place in two stages instead. The two most common reasons that only one stage is installed are:

- A wish to reduce investment costs
- The operation conditions have changed for the compressor, increasing the temperature difference from the original design specifications

Based on the normal operating for freezing purposes the energy savings potential for installing a two stage solution for large pressure changes is normally 10 – 20 % of the electricity used by the compressor. The relevance of this action is further described in section 2.3.1.1.

Diagnosis of situation:

Only a few steps are needed to determine if there are potential for a two stage solution.

- Find the suction and discharge pressure for all compressors stages at the facility.
- Calculate the pressure ratio by dividing the discharge pressure with the suction pres-sure.
- If the pressure ratio is larger than 6.0, there is a valid potential for a two stage solution.

Changing the compressor system from one to two stages is a major change and it is necessary to include an expert or supplier early in the project.

1.3.3 Recover heat from oil cooling

Oil cooling is essential for a refrigeration plant to work properly, but there are also large amounts of energy and capacity wasted on oil cooling. This energy can be used to generate hot water instead of discharging it to the cooling tower.

Under normal conditions approximately 10% of the heating energy from screw compressors comes from oil cooling, which can be transformed into hot water at 60˚C.

Diagnosis of situation:

If there are one or more screw compressors in the refrigeration plant, there is a potential for making hot water from oil cooling.
The most important thing to investigate is if the hot water can be utilized anywhere and generate a saving or in other way be of use.

1.3.4 Change of flat belts to high efficiency belts

Piston compressors in Vietnam are often driven by belts of the flat belt type. It is not uncommon that these belts have waste of power in the ratio of 10%, both because they are inefficient and not properly maintained.

A simple change of the belt type to a wedge belt, cogged belt, synchronous belt or other types of high efficiency belts, can lower wasted energy to as little as 1% of the total electricity used by the compressor.

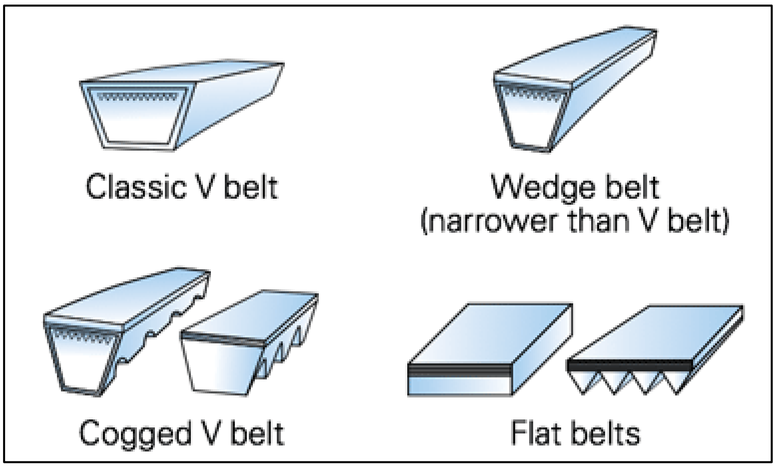

Figure 7. Schematic drawing of the most common belts.

There is a very high saving potential in this measure, which is about 10% of all electrical energy used by the compressors in the refrigeration plant using belt drives. Some refrigeration plants do only have piston compressors which give a very high saving potential. Age and lack in maintenance will increase the loss in the belts, increasing the potential by a replacement.

1.4 Condenser

In the condenser, heat from cooling processes is rejected. For chillers, the condenser can take different forms. The dircet kind where refrigerant is condensed directly in the ambient:

- Dry condenser: Heat of condensation is released directly to the ambient air through heat exchange **without** the use of water.

- Evaporative condenser: Heat of condensation is released to the ambient air through heat exchange **with** the use of water. A film of water on the outside of the condenser absorbs the heat and evaporates into the ambient.

Alternatively, the condenser can also be a water chilled heat exchanger. If this is the case the energy of condensation can be released to the ambient via a cooling tower:
- Dry cooling tower: Heat from water is released to the ambient air through heat exchange **without** the use of water.
- Wet cooling tower: Heat from water is released to the ambient air through heat exchange **with** the use of water. A film of water absorbs the heat and evaporates into the ambient. See Figure 7.

refrigerant is condensed against ambient air.

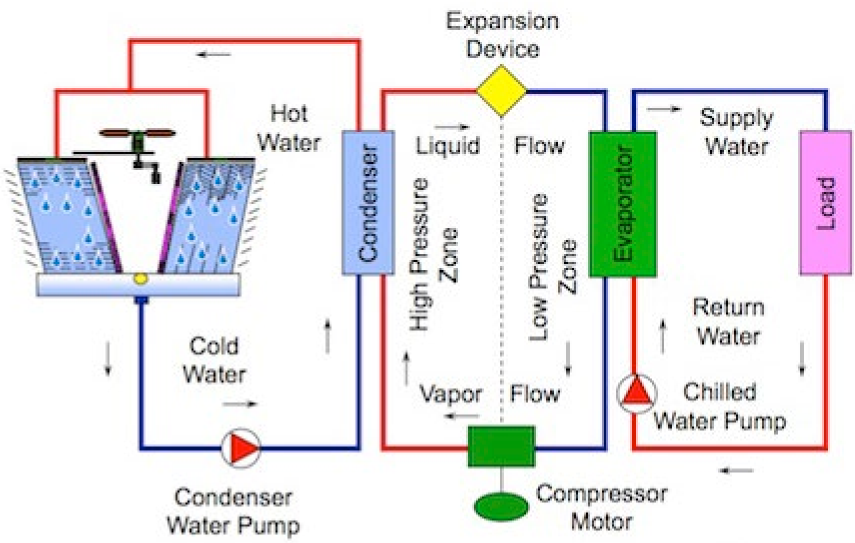

Figure 8. Illustration of chiller where condenser is a water chilled heat exchanger [3].

1.4.1 Larger water chilled condenser

The condensing temperature of the refrigeration plant is of major importance for electricity consumption of the refrigeration plant. Electricity consumption increases by 3% for each degree the condenser temperature rises.

It is often observed that condenser pressures are too high in the industry, which is caused by several reasons:
- Poorly maintained (fouled) condensers.
- Air in the condensers
- Too small condensers
- Inefficient operation of the condensers
- Fixed condenser pressure operation

In practice this means that if the temperature difference between the outlet of the chilled water and refrigerant condensation temperature is greater than 2 ºC, there is room for improvements, since 2 ºC delta-T is the optimal heat exchanger design. In Figure 8 this is illustrated where the condensation temperature can be lowered by 5 ºC.

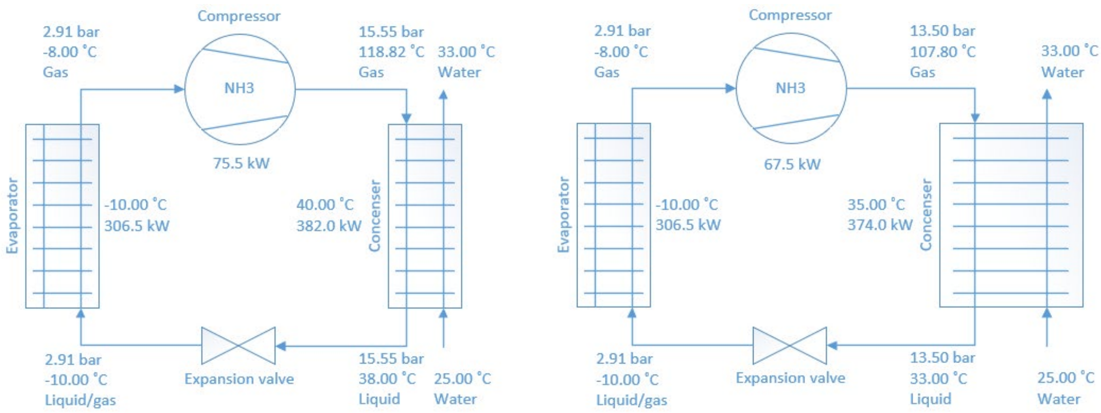

Figure 9. Principle drawing of two refrigeration plant including technical data. The only difference is the size of the condenser. Reducing the condenser temperature from 40 ºC (left part of figure) to 35 ºC (right part of figure) by increasing the size of the condenser, as much as 15% of the electricity consumption for the compressor can be saved.

The saving potential for this measure is high since it will influence all cooling devices connected to the condenser. It is typically possible to save 5% to 15% of the total electricity used for refrigeration if all condensers are changed or renovated.

Investments in such changes will however often be medium to high thus leading to a medium to high payback period for the measure.

However, if the measure is introduced at the same time as more refrigeration capacity is introduced, investments and payback period for the extra size of the condenser might be low.

Diagnosis of situation:

It is easy to detect if there is an energy saving potential by increasing the condenser size.

- Determine condensation temperature (using discharge pressure).
- Determine cooling water temperature out of condenser.
- Compare the two temperatures and see if it is greater than 2 ºC.
    - If yes, there is potential.

The methodology above describes a refrigeration plant with a traditional condenser with refrigerant on one side, and cooling water in the other. If the condensation of the refrigerant takes place directly in the cooling tower (no intermediate water loop), see section 1.4.3 for the size of cooling towers.

1.4.2 Install a desuperheater

Desuperheating is the cooling of the refrigerant from the compressor outlet temperature, easily more than 80 ˚C, down to the condensation temperature. Desuperheating takes place in all refrigeration plants. The question is whether the heat released can be utilized. Approximately 10-15% of the total condensation energy, roughly equivalent to 60% of electricity used by the compressors, can be used to heat water up to temperatures around to 60˚C for cleaning purposes etc. It can be added to existing systems or planned in new installations and the pressure loss in a correct designed unit is neglectable.

The production of hot water will not have any operating cost after installation and can replace an existing production of hot water. If hot water is not used at the production site, it can be sold to nearby people or companies.

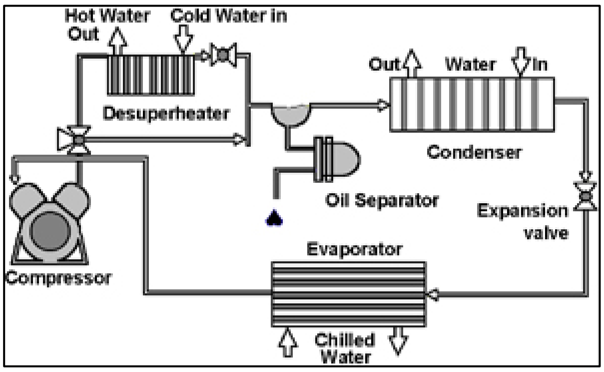

Figure 10. Traditional cooling circuit with a desuperheater added.

The saving potential is highly dependent on the current use of hot water and whether all the heat can be utilized.

The economic saving will be highest if the existing production of hot water is based on oil, LPG or electricity, and will be significantly lower if it is made from biomass or other low cost fuels.

Also, some electricity consumption for the compressor in the refrigeration plant can be saved as the condenser capacity increases.

Diagnosis of situation:
The first thing to determine is if hot water is used at the facility. If not, it should be clarified if hot water can be sold to neighbouring companies? If one of these possibilities is open, calculation can go to the next step where a specialist can calculate the exact potential and find a price for the equipment and installation.

The potential for making hot water from a desuperheater is present at all refrigeration plants. The potential production and temperature can be found from the refrigerant discharge temperature.

CASE

Underfloor heating system installed in a cold store. This system uses heat recovered from the refrigeration plant and costs close to nothing to run.

1.4.3 Increase size of cooling tower

If the capacity of the cooling tower is too small, the cooling water will be warmer than necessary, leading to a higher condensation point for the chiller and hence a higher energy use. The capacity on the cooling towers can easily be increased with another one in parallel with the existing ones.

The main reason for cooling towers being too small are:

- They were originally designed to be too small to reduce investment costs.
- The load on the refrigeration plant has increased, but the cooling towers have not been updated.
- A not optimal design of the cooling tower.
- The footprint of a new cooling tower is too big and cannot easily fit at the facility.

If the temperature of the cooling water can be lowered, the compressors will save energy, and the cooling towers will increase theirs. In total there will be energy saving.

In the facilities with potential, the saving will normally be 5-15% of the electricity used by the compressors.

Diagnosis of situation:

To determine if there is a potential for energy savings, follow the steps below.

For water chilled cooling tower/ evaporative condenser:

- Determine the temperature of the cooling water returning from the cooling tower to the condenser. For evaporative condensers, find the condensation temperature from the condensation pressure.
- Find the wet bulb temperature of the ambient air. Sometimes this can be read on the control panel of the cooling tower. If not, measure the dry bulb temperature and humidity and calculate the wet bulb temperature.

- The temperature difference between the return water temperature/condensation temperature and the wet bulb temperature should be around 3 ºC, and up to 5 ºC can be accepted. If the temperature difference is higher, there is a potential for energy savings.

For air chilled cooling tower/ air chilled condenser:

- Determine the temperature of the cooling water returning from the cooling tower to the condenser. For air chilled condensers, find the condensation temperature from the condensation pressure.
- Find the dry bulb temperature of the ambient air. Sometimes this can be read on the control panel of the cooling tower.
- The temperature difference between the return water temperature/condensation temperature and the dry bulb temperature should be around 5 ºC, and up to 7 ºC can be accepted. If the temperature difference is higher, there is a potential for energy savings.

After detecting the potential for energy savings, the next step is to contact a supplier and get their help to calculate the actual energy saving potential.
If new cooling towers/condensers are bought, this could also be a good time to invest in VSD and change the control system of all the cooling towers.

NOTE: If a large cooling system is in lack of capacity and expansion is needed, it is often more beneficial to install more condenser capacity than more compressor capacity!

1.4.4 Use floating condensation

In an energy optimal solution, the condensation temperature varies according to the outside temperature instead of being constant over day/week/year. The condensation temperature is of major importance for the electrical consumption in the refrigeration plant.

When the outside temperature is low, the condensation temperature should be low as well. This can save large amounts of energy and be implemented by regulation measures.

In general, 3 % of the electrical consumption of a refrigeration plant can be saved for each degree the condensation temperature is lowered. Be aware to keep the operations inside operational envelope of the compressor, meaning the a minimum condensation pressure is required.

The energy saving potential for this measure will be between 10 – 20% depending on the workload of the facility and how much ambient conditions vary. Equipment operating continuously has a larger potential than equipment operating only in work or peak hours.

Diagnosis of situation:
Normally, the operating personnel knows if the condensation temperature varies. If not, look through the data logs (if available) and see if the condensation temperature is fluctuating over day/week/year (or read the temperature / pressure on the pressure side of the compressor on a cool day).

After detecting if there is a potential, the next step is to assess how big it is. If there are detailed data logs from the refrigeration plant, it can be calculated from this, otherwise there must be assumed some general workloads for the refrigeration plant. If you are skilled with thermodynamic calculations, you can do it yourself; otherwise, an expert must do it. Next step is to contact a specialist or supplier.

1.4.5 Direct condensation of ammonia in evaporative condenser

Direct condensation of ammonia in evaporative condensers is preferred from an energy standpoint over indirect cooling via a water circuit in a cooling tower.

By direct condensation of the ammonia the pinch temperature between the ammonia and water circuit can be ‘saved’. If the condensing heat exchanger between the water and ammonia is poorly designed, the pinch temperature can be up to 5 ºC, which means the potential electrical saving can be on the order of magnitude of 15%.

For existing systems, the business case of changing the condenser is a bit challenging when only looking at energy cost savings, but still relevant. The most important driver would be that the cooling capacity of the entire system is increased significantly and that can have significant value or avoid costs of adding compressor capacity.

1.4.6 Correct placement of condenser

If the condenser is air-cooled, it should not be placed directly in sunshine. Direct radiation from the sun will raise the condensation temperature leading to an increased electrical consumption of the compressor.

The electricity consumption can be decreased by 3% for each degree the condenser temperature is lowered.

1.4.7 Remove fouling on cooling towers/evaporative condensers

For cooling towers/evaporative condensers it is important to make sure that there is not a large buildup of sediments on the heat transfer surfaces (e.g. coils in evaporative condenser). If this is the case, it will lead to reduced heat transfer capabilities which means condensation temperature is raised.

The electricity consumption can be decreased by 3% for each degree the condenser temperature is lowered.

Diagnosis of situation:

Check if there’s is large build of foulant (micobiological, scale, etc) up on wet condensers. If it is the case, contact supplier for most suitable way to remove it.

1.5 Evaporator

The evaporator is where the cooling is ‘produced’. Making sure that it is operated in an optimal way is crucial for the overall efficiency of the system.

1.5.1 Larger evaporator

The suction pressure of the refrigeration plant is also of major importance for electricity consumption as energy consumption increases by 3-4% for each degree the evaporating temperature is lower than necessary.

It is often observed that evaporator pressures are much too low compared to the required cooling temperature in the industry, which is caused by several reasons:

- Too small evaporators
- Drums or spirals are used instead of plate heat exchangers (drums/spirals = old and poor technology)
- Moist (ice) has built up on the evaporator.

In practice this means that if the temperature difference of the two mediums at the coolest point is greater than 2 ºC, there is room for improvement, since 3 ºC delta-T is the optimal design point.

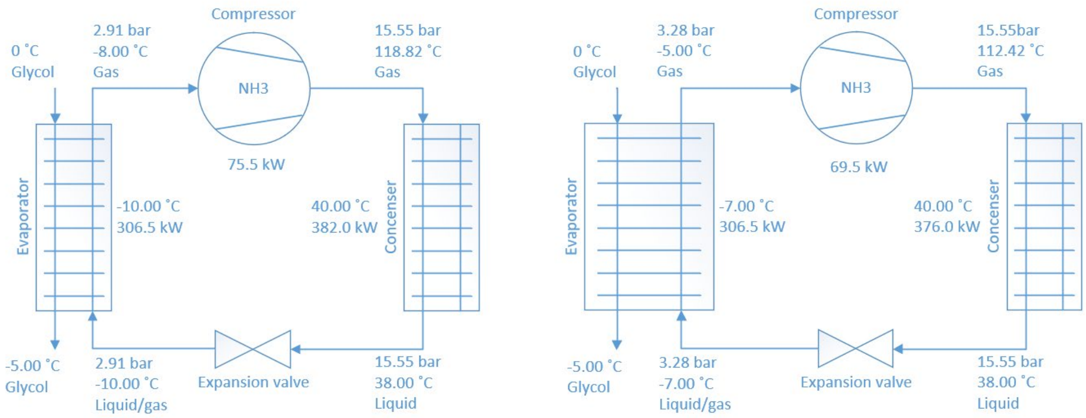

Figure 11. Principle drawing of two refrigeration plant including technical data. The only difference is that the size of the evaporator. Increasing the evaporator temperature from -10 ºC (left part of figure) to -7 ºC (right part of figure) by increasing the size of the evaporator as much as 9% of the electricity consumption for the compressor can be saved.

The energy saving is dependent on the temperature increase there can be obtained at the compressors suction point. A saving of 5-15 % will normally be achievable by Vietnamese companies.

Diagnosis of situation:

In cooling systems with only few evaporators, the operator may do the diagnosis on his own through the following procedure:

- Determine the evaporating temperature in the evaporator (using the suction pressure and calculating the temperature for the specific refrigerant)
- Find or draw the complete network of evaporators (units using cooling).
- Determine required temperature at the cooled process or room (required room temperature, required water temperature etc.). It is important that the "required" temperature is registered according to what is needed and not the cooling temperature of the medium delivering the cooling service.
- The lowest temperature difference between the evaporation temperature and the process / space temperature should, as a rule of thumb, not be larger than 3 ºC.

If there are multiple units on the refrigeration system, contact a specialist to help with the diagnosis of the potential. If the system is simple, check for potential via own investigations. If temperature difference between room temperature and refrigerant evaporation temperature is higher than 5 ºC, contact a specialist or supplier.

It is also important to mention that a larger evaporator (air cooler), with a smaller temperature difference between room temperature and refrigerant evaporation temperature, can reduce problems with ice building up on the evaporators in cold stores.

1.5.2 Variable suction pressure

If cooling demand varies with ambient conditions, varying the suction pressure should be considered to increase efficiency.

An example of this is storage cooling, where the cooling demand varies throughout the year. Here it is possible that the cooling demand in the colder months can be met with a higher forward temperature of the chiller, which will lead to energy saving on the compressor in the cold months.

Diagnosis of the situation:
One way to test is to see if the current equipment (e.g. heat exchangers in storage cooling systems) can handle a higher forward temperature in the cold months. This can be done by raising the forward temperature of refrigerant and seeing if the required cooling still can be delivered. If this is the case, it can consider raising the forward temperature in the cold months.

1.5.3 Constants pressure valves should be avoided

Regulating control valves in the system, determines the operating mode. Constant pressure valves on chillers lower the suction pressure and limits the capacity. They should only be used when necessary to avoid freezing and when this is not possible by standard regulation.

CASE

The evaporation pressure of the cold storage is set at 0.95 Bar $_a$ (corresponding to an evaporation temperature of -35ºC). This evaporator pressure is quite low and reduces the coefficient of performance (COP) of the compressor to 1.78 kW $_{thermal}$/kW$_{elec}$.

The factory increased the pressure of the cold storage to 1.35 Bar (temperature -30ºC/ 31ºC), leading the COP of the compressor is 2.18 kW heat/kWelec.

- Reduce power consumption by 18% or save 52,896 kWh/year
- Annual cost savings of 84 million VND
- Reduce GHG emissions by 48 tons of CO_2/year
- Immediate payback time

1.6 Distribution of cooling / process consumption

1.6.1 Avoid cold water production from ice

In Vietnam a lot of ice is used to produce chilled water, where ice is simply mixed with water. This is a very inefficient way of producing chilled water, and a lot of excess energy is used because of this method. The reason is that production of ice requires much lower evaporator temperature than direct production of ice water.

Instead of using ice, the water should be cooled directly in a designated chiller installed for that purpose only. If there is large variation in consumption, a buffer tank can be installed.

If a new chiller is installed to produce cold water, or one of the existing ones is rebuilt, the energy saving would at least be 40% of the electricity used by the compressor.

Diagnosis of situation:

Investigate how much ice is used to produce cold water. In daily operation it could be a bit difficult to measure. It suggested assigning a person to keep track of the numbers of baskets of ice used.
If more than 1500 kg of ice per hour is used, investigate the energy savings potential of a designated chiller.

1.6.2 Control of freezer temperature

Freezers and small cold stores are often used without taking notice of the operating conditions. If the temperature is lower than required, the energy consumption will be higher than necessary. The temperature should regularly be checked to make sure that all units are operating as planned.
Be aware of the common misconception that the capacity will increase if the temperature is lowered.

Diagnosis of situation:

- The first thing to do is to check what temperature the products in the freezer require.
- If the set point of the freezer is unnecessarily low, raise the temperature to match the product demand.

1.6.3 Design of consumers

All users of refrigerant or chilled water/glycol should be designed to have the lowest possible temperature difference to ensure economical use of the refrigeration.

If refrigerant is used directly, the temperature difference to a liquid media should be no more than2 ℃, while it should be no more than 5 ℃ to a gas phase media. If water or glycol is used, the temperature differences should be no bigger than 2 ℃ and 4 ℃ respectively.

If a cooling system serves several consumers, there could be different temperature requirements between the consumers. It should be assessed which consumer that set the limitation on cooling temperature. If the one consumer for example sets the limit the for the forward temperature of cooling supply, and this consumer has a poorly designed heat exchanger, there can be significant savings by replacing this heat exchanger and raising the evaporation temperature.

1.6.4 Direct cooling

If it is possible to use direct evaporation of the refrigerant, e.g. ammonia for direct space cooling instead of indirect space cooling as shown on Figure 1 it is preferable. This is better as it potentially allows for a higher evaporation temperature.

The energy potential can be significant as electrical consumption can be reduced by 3-4% for each degree the evaporating temperature is lower than necessary. Furthermore, increasing the evaporation temperature can lead to increased capacity of the cooling machine.

One must take safety concerns into account if ammonia is used directly.

Normally it would be economically attractive to change the existing system if energy savings are not only positive input in the business case. But it is relevant if changes are needed for other reasons.

1.7 Maintenance / behavioral strategies

There can be big energy savings if the correct behavioral strategies are implemented.

1.7.1 Adjustment of ice production

Production of ice uses a lot of energy, and all ice that is produced and not used, is a waste of energy. When ice is stored, it will slowly melt, which is a waste. Make sure that the production of ice is adjusted to the need instead of filling the storage. Adjust the production so that all the ice is used at the end of each workday, and especially before the weekends.

1.7.2 Night reduction

Equipment and production facilities can use a lot of energy even when no production is taking place. This kind of idle energy use should be as low as possible. Make sure that all equipment is turned off when it is not used. All systems should be controlled only to use energy when it is needed. An example is to turn off the air conditioning between working periods.
An easy way to detect potential savings is to take a tour through the facility at night.

1.7.3 Close doors / automatic gates

A very simple measure is to keep all doors, windows and gates always closed. When there are openings, heat and moisture will get in and increase the use of air conditioning. This may seem like a small thing, but the savings are real, and the effort to change it is very small. It is not only doors to surroundings that should be kept closed; also, doors between different temperature zones should be closed when not in use. This can also minimize the buildup of ice dramatically.

1.7.4 Cleaning of heat exchangers

Heat exchangers will always be at risk of fouling, which can be caused by many different types of dirt or salts. Inside the heat exchanger there can be a layer of fat, oil, grease, dust, pollen, scaling and so on. Even a thin layer of fouling will reduce the heat transfer coefficient significantly and increase the energy consumption.
All heat exchangers should be inspected and cleaned on a regular basis according to their risk of fouling.

1.7.5 Technical insulation

The insulation of both hot and cold equipment should always be sufficient and maintained. The insulation can easily be damaged or removed during rebuilding or repair. Normal problems are that people step on the insulation, it is removed, or it is insufficient at technical parts as pumps and vents, or it is wet.
The solution is to review all hot and cold equipment and control that all parts have proper insulation all the way from source to user.

1.7.6 Defrosting

When icing is present on heat exchangers and other heat transferring equipment, the energy consumption will increase from the ideal situation. Be aware to defrost all equipment regularly to lower energy consumption and increase capacity. The period between defrosting is highly dependent on the equipment and should be monitored regularly.

It is important that the drip time after defrosting is sufficient, so the surfaces become dry and frost free.

1.7.7 Check for corrosion

Check If there are signs of corrosion. This can be a sign of poor insulation or water condensation problems. Poor insulation leads to unnecessary heat losses from the system.

2 Selection and equipment for new cooling-installations

Cooling machines used for cooling purposes can be based on different refrigerants, refrigeration cycles and different equipment. This section aims at providing guidance on selection of type of cooling machine for a specific need.

2.1 Cooling demand influence

2.1.1 Reduce the cooling demand before designing new plant

Prior to ordering any equipment it is important to analyze the cooling demand and optimize it. Here such things as the following could be considered:

- Have the end users been optimized regarding cooling supply temperature. Maybe the end users can tolerate a higher forward cooling temperature if their heat exchanger design is optimized. This can lead to substantial OPEX savings.
- Can the cooling be supplied by heat recovery from another process at the site, that needs to heat from a low temperature? This could reduce the total required cooling demand.

2.1.2 Find and challenge the new cooling demands

Once the cooling demand has been internally optimized, the next step is to analyze the total cooling demand:

- What is the total required cooling supply? And what is the required cooling temperature?
    - If the cooling demand is charactered by large spikes over a short period of time, consider if the cooling demand should be taken partly by buffer capacity.
- Are the differences in the required cooling temperatures so large that it makes sense to split the cooling supply in different temperature levels?
- Does the cooling demand fluctuate significantly over the day or year?
- Are there low-temperature heat demands at the site, that can be covered by heat recovery from the cooling system via desuperheater or oil-cooler?
- Is production at the site going to increase in the coming years or is the site going to expand in terms? This could greatly influence the cooling demand in the future.

2.1.3 Investigate alternative solutions

When the cooling demand and supply temperature has been established, it is important to consider the ambient conditions of the site:

- Is the required cooling temperature high enough, that it will make sense to use free cooling part of the year? (this is especially relevant in colder regions)

2.2 Choose the right refrigerant

When the cooling demand at the site has been established, the next step will be to consider equipment. As a first step, one can consider if certain refrigerants are wanted/unwanted. Therefore, a brief introduction to different refrigerants is given in this section.

2.2.1 GWP and ODP

Besides the performance of a refrigerant, it is also important to address the environmental effect a refrigerant has. Each refrigerant has a GWP-value (Global Warming Potential) which describes how damaging the refrigerant is to the environment in a period of 100 years. It compares the greenhouse warming to the greenhouse warming if 1 kg of CO_2 is emitted. The GWP should be as low as possible [4].

Each refrigerant also has an ODP-value (Ozone Depletion Potential). The ODP is a measure of how much a refrigerant depletes the stratospheric ozone layer. The ODP is measured relative to the refrigerant R11 which is defined to have a ODP of 1 [5].

Viegand Maagøe

2.2.2 Types of refrigerants

With the Montreal Protocol, which was effective from 1989, it was agreed to phase out refrigerants that have high OPD-values such as chlorofluorocarbons (CFCs). These were gradually replaced by hydrofluorocarbons (HFCs) that have a much lower ODP-values [6,7].

HFCs have then been widely used as they have low construction costs, but they have a very high GWP-value. Due to the high GWP-values of HFCs it was specified in the Kyoto protocol that use of HFCs should be limited [8].

Focus have therefore switched to natural refrigerants such as ammonia, CO_2, hydrocarbons, and water vapour. They have insignificant effect on the greenhouse warming and ozone layer. Furthermore, natural refrigerants are also available in unlimited quantities, inexpensive and economical to use and likewise are very energy-efficient [9].

In Table 1 some common refrigerants are shown along with their ODP- and GWP-values.

	Type	Refrigerant	ODP	GWP*	
Synthetic	CFC	R-12	1	Very High	10,910
	HCFC	R-123	0.012	Low	
	HFO	R-1234ze	0	Ultra-Low	1
	HFC	R-134a	0	High	1,430
	HCFC	R-22	0.05	High	1,810
	HFC	R-32	0	Medium	675
	HCFC	R-401a	0.027	Medium	
	HFC	R-404a	0	Very High	
	HFC	R-407a	0	High	
	HFC	R-407c	0	High	
	HCFC	R-408a	0.016	Very High	
	HCFC	R-409a	0.039	High	
	HFC	R-410a	0	High	2,090
	HFO	R-454b	0	Low	466
	HCFC	R-502	0.18	Very High	
	HFC	R-507	0	Very High	
	HFO	R-513a	0	Medium	631
Natural	Isobutane HC	R-600a	0	Ultra-Low	
	Ethane	R-170	0	Ultra-Low	
	Propane	R-290	0	Ultra-Low	
	CO^2	R-744	0	Ultra-Low	1
	Ammonia	R-717	0	None	
	Water	R-718	0	None	

Table 1. Overview of common refrigerants with their ODP and GWP potentials [10].

2.2.3 Converting to a more environmentally friendly refrigerant

With the phase out of some types of refrigerants, for example the CFC R22, other refrigerants have been developed as replacements in existing equipment. This means that instead of replacing an entire system with all the different components, in some cases the refrigerant can just by replaced.

However, as the substitute refrigerant has slightly different properties the capacity and efficiency of the system can be affected [11]. Contact a local supplier to get more detailed information on possible refrigerants substitutes for your unit.

2.2.4 Safety measures

An important thing to consider when choosing refrigerant for a new cooling machine is the safety measures that must be considered. For refrigerants this is especially toxicity and flammability. Toxicity is a measure of the concentration and exposure time for a refrigerant to be harmful. If a refrigerant is harmful in small quantities over a short period of time it is viewed as highly toxic. The flammability of a refrigerant is its capability of igniting and combusting. One of the things characterizing a refrigerant's flammability is the lowest temperature at which it can ignite – the lower the higher flammability [12].

Depending on the toxicity and flammability of a refrigerant, different safety measures have to be installed in the machine room. Below in Table 2 different safety classifications are illustrated.

	lower toxicity	higher toxicity	
higher flammability	A3	B3	LFL ≤ 0.10 kg/m^3 or heat of combustion ≥19 000kj/kg
lower flammability	A2 A2L*	B2 B2L*	LFL ≤ 0.10 kg/m^3 and heat of combustion ≥19 000kj/kg
no flame propagation	A1	B1	no LFL based on modified ASTM E681-85 test
	no identified toxicity at concentrations ≤400 ppm	evidence of toxicity below 400 ppm (based on data for TLV-TWA or consistent indices)	

*A2L and B2L are lower flammability refrigerants with a maximum burning velocity of < 10 cm/s.

Table 2 Safety classification from ASHRAE Standard 34 [12].

2.3 Choose the right refrigeration cycles

Refrigeration systems can be designed in many ways depending on the application of the system. In this section the most basic systems designs are described.

2.3.1 Vapour-compression refrigeration cycle

The most common form of a refrigeration system is that of the single stage vapor-compression cycle. It consists of the main components; compressor, condenser, evaporator, and expansion valve as introduced in section 1.1.

Below on Figure 11 an illustration of the ideal vapour recompression cycles is illustrated.

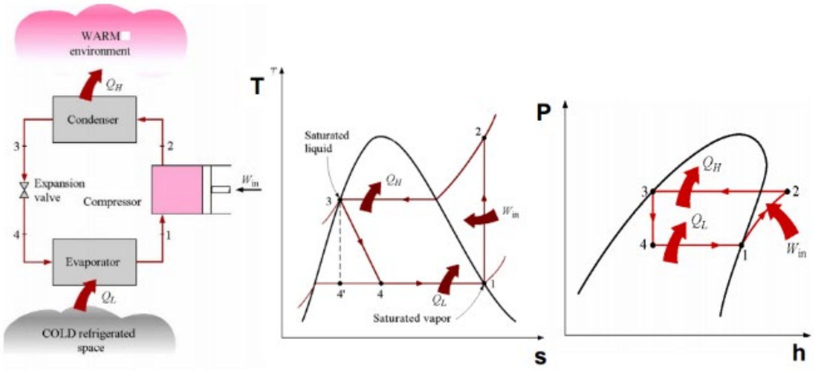

Figure 12. Ideal vapor-compression cycle [13].

2.3.1.1 Multistage systems

If the temperature lift becomes large the performance of the single stage vapor-compression cooling machine becomes quite ineffective as the compressor work will increase significantly. To overcome these multistage systems are recommended. The basis of the multistage system is to add several compressors in series, to decrease the overall compressor work of the system [14].

Besides from increasing compressor work, the multistage refrigerant system can also be good to use If cooling is required at several temperature levels at the site. If a freezing process for example requires an evaporation temperature of -30°C and another demand at the site requires water at 2°C, this can be met by having an intermediate evaporator included in the system, which will increase overall system efficiency [14]. This is illustrated on Figure 12.

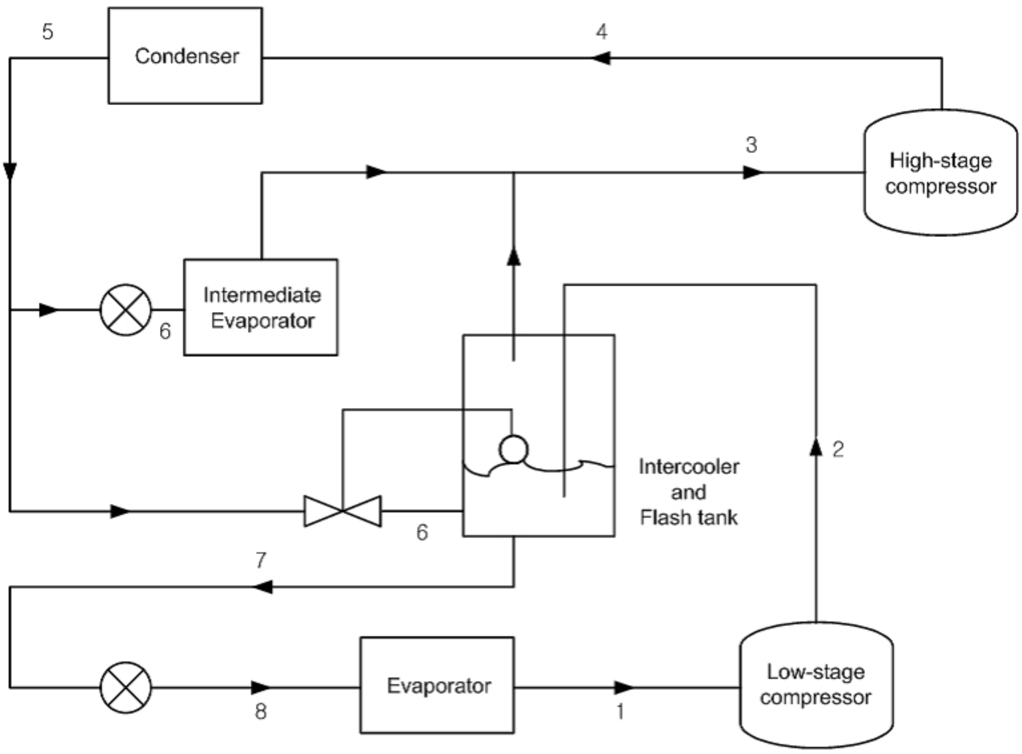

Figure 13. Two-stage refrigeration system with intermediate evaporator [15].

When the cooling demand is relatively small a single stage system is effective down to temperatures in the range of -10°C to -30°C. For systems larger than 1500 kW multistage systems should be considered below -10°C.

2.3.1.2 Economizer

An economizer on a refrigeration system is used to sub-cool the main flow of refrigerant to the evaporator with another sub stream of the refrigerant. This sub stream enters the compressor at an intermediate temperature level. The purpose of the economizer is to increase the cooling capacity of the cooling machine. The economizer requires that the compressor has an extra intermediate ‘economizer’ entrance [16]. This is primarily applicable on screw compressors. The larger the pressure differences between evaporator and condenser and the large cooling demand the more beneficial it is.

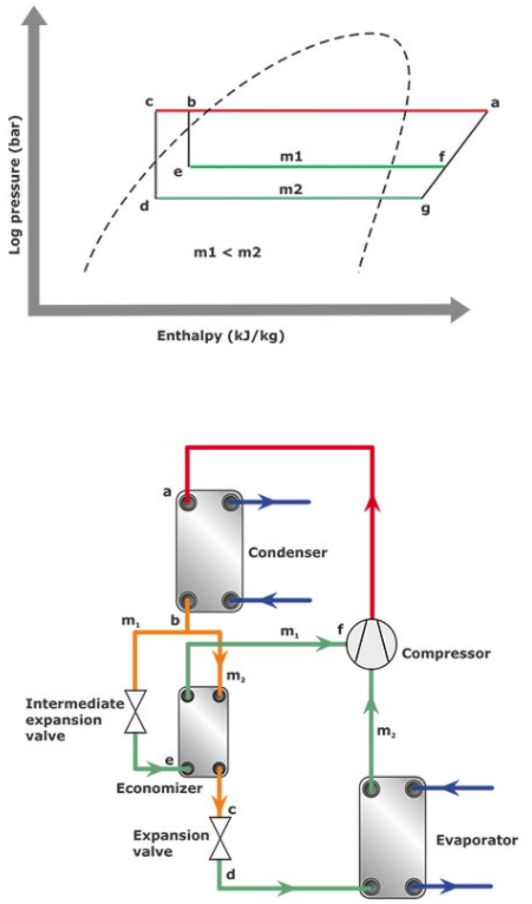

Figure 14. Economizer on refrigeration system [13].

2.3.2 Transcritical systems

Another type of refrigeration cycle is the transcritical cycle. This is a type of cycle where CO_2 is used as the refrigerant. The main difference from the vapor-compression cycle is what happens on the high-pressure side. At temperatures higher than 31°C CO_2 cannot condense. Therefore, what is called the condenser in vapor-compression cycle is called a gascooler in a transcritical cycle CO_2-cycle [17].

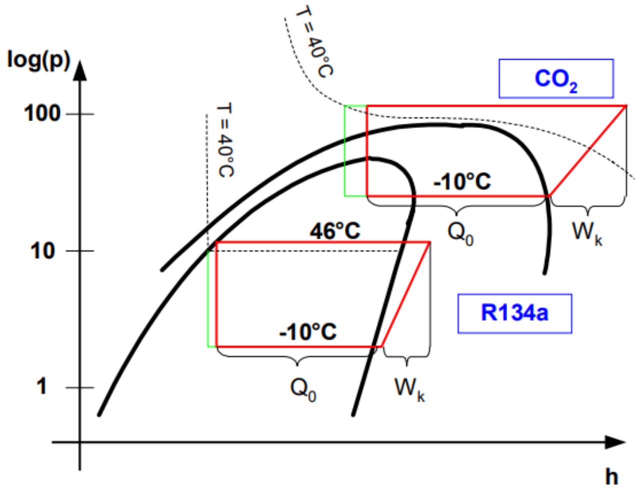

Figure 15. Transcritical CO_2-cycle compared to traditional vapor-compression cycle with R134a as refrigerant [17].

As seen on Figure 14 the transcritical CO_2-cycle operates at much higher pressures than the vapor-compression cycle. Another difference is that while condensation in vapor compression cycle happens at a constant temperature, the temperature varies in the gas cooler leading to a so-called temperature glide. This temperature glide means that the CO_2-cycle can be more suitable for heat recovery applications.

Systems using CO_2 as refrigerants are generally cheaper and better for small cooling demands compared to ammonia. Furthermore, CO_2 has fewer safety regulations as it is non-flammable and non-toxic compared to ammonia. The main disadvantage is that the system generally is less energy efficient.

2.4 Other things to consider

This section provides a brief overview of other things that should be considered when buying new equipment.

2.4.1 Economic considerations

When deciding on which equipment to order, it is important to make a complete economic analysis over the lifetime of the equipment or at least a 10-year period taking all CAPEX and OPEX into account. A good tool here to compare different solutions is the NPV. To conduct this analysis, one will need:

- A forecast on production amounts/possible expansions and thereby a forecast on cooling demand
- A forecast on energy prices and development of all relevant taxes
  - Maybe new laws are under development that can affect energy prices/energy taxes.
- All operating costs for maintenance, spare parts, service, refrigerant, oil, etc.

It is common that energy efficient solutions have higher investment costs and lower operating costs. It is therefore important to show the total cost of ownership (TCO[1])over a period to find the optimal solution.

2.4.2 Legislative considerations

One will also have to take legal concerns into account:

- Are some refrigerants going to be banned soon or heavily taxed? (e.g. Reduction in R22 import quota per CIRCULAR 05/2020/TT-BCT. Or reduction in CFC and HCFC usages)

[1] TCO (Total Cost of Ownership) do not have a strict definition but is more general level of approach. It has been known in many forms and was first formalized by the US Department of Defense in the late 1990s. A popular definition is "*the total cost of acquiring, using, managing and withdrawing an asset over its entire life cycle*".

- Is environmental approval needed for the equipment? (e.g. TCVN 6104-1:2015, equivalent to ISO 5149-1:2014)
- Are there any noise requirements for the area that should be considered?
- Is a building permit needed?

2.4.3 Environmental considerations

On environmental side things to consider could be:

- What are the carbon emission factors for the electricity forecasted to be? And what will the emissions be over the lifetime of the equipment?
- Does the company have a climate policy or other strategy goals that influence the decision making?
- Does the company have a policy on refrigerants?

2.4.4 Security of supply

The stability of cooling supply can be quite crucial for some companies, therefore consider:

- How stable is the electricity supply? Is a back-up generator needed?
- Does the company need a back-up chiller if one chiller fails? (n+1)
    - This also concerns other crucial parts such as pumps.

2.4.5 Practical considerations

Other things to consider are:

- Is the equipment going to be placed in a corrosive environment, e.g. close to the sea?
- Is a back-up chiller needed so one chiller can be taken out for service?
    - This also concerns other crucial parts such as pumps.
- Is there a limited space where the equipment can be placed?

2.4.6 Maintenance

It is important to install a proper maintenance system based upon input from the equipment suppliers in terms of changes of lubrication, change of sealing and other regular maintenance issues. Maintenance must be preventive and not when the system is broken down.

2.4.7 Documentation

For the correct operation and maintenance of the refrigeration plant, it is crucial to have all relevant documentation, such as operation and maintenance manuals, P&ID, available in a safe, accessible place.

It is important to have a tag numbering system securing correct identification of all components.

2.5 How to proceed

Sections 2.1 - 2.4 gives a very brief overview of things to be considered when ordering a new system.

The main take aways of the sections are:

1. Make sure that the cooling demand at the site has been optimized and know if the cooling demand is set to increase/decrease in the coming years.
2. Consider if some refrigerants are more or less wanted and some cycle designs are preferred over others (read section 2.2 and 2.3 for more detail)
3. Take economical, legislative, environmental, and other considerations into account (read section 2.4 for more detail)

4. Go through the points in section 1 of this report to check if all the new equipment and solutions are the best available. It is when installing new equipment that energy efficient solutions are the cheapest and easiest to build in.

To answer these questions and get more into detail it can be a good idea to contact an unbiased local consultant. This consultant should be able to contact local suppliers of cooling systems and be able to give advice on pros and cons of different systems.

3 The procurement process for new cooling installations

Procurement of new cooling installations is a significant investment project for most industries and necessitates a careful planning work to secure sustainable and cost-efficient solutions. The scale of the project, and hence investment, can vary greatly, and it is important to select procurement process relevant to project size. In this section the process for a large investment is described.

To do this, the procurement process should follow the steps below:

1. A pre-feasibility phase
2. A feasibility phase
3. A tendering phase
4. A tender evaluation phase

Later steps when implementing, testing, and commissioning the refrigeration plant are not described in this context.

3.1 Pre-feasibility phase

The aim of the pre-feasibility phase is to define the project to carry out and evaluate alternative overall solutions so as it can be concluded what the most attractive way forward will be.

The dilemma most industries must challenge in this phase is whether to select a cheap, low-efficient solution or a more expensive and more efficient solution with lower operating costs. It is recommended to assess these alternatives carefully and well documented for the management to make the right choice.

Another consideration to be made before the purchase process commences is whether the current set-up in the production will also be the right one in the future.

The easiest way forward will most often be to install new equipment without further consideration, but more careful investigations might uncover alternative solution strategies. As such, a pre-feasibility phase should carefully assess and document the design basis for the project and compare various elements in the solution strategy, by example:

1. **What is the purpose of the project?**
   It is important to be precise about for which reasons a new cooling installation is to be considered?

   The most common reasons for initiating a cooling-project will be the need for more capacity or because the company experience severe outages in cooling generation.

   But a new cooling installation could also offer a range of other benefits, such as
   - Reduced operational costs (including energy, staff, and maintenance)
   - Increased availability (less hours of production stop due to lack of cooling supply)
   - Cooling production capacity to match better with the demand.
   - Improved working environment
   - Reduced emissions to the local environment
   - Reduced carbon footprint
   - Compliance with current regulation

- Increased market value of the product as a result of lower environmental impacts.

The combined value of these benefits could very well supersede the value of the energy cost savings. It is important, therefore, to consider these already in the pre-feasibility study and highlight those that are deemed most important.

But also, a strategy to become more energy- and cost efficient or to reduce carbon emissions can be the reason for starting a project.

2. **What is the scope of the project?**

   A cooling-project might be simple replacement project, i.e. a replacement of a worn-out compressor or evaporative condenser. But a cooling project might also comprise a completely new refrigeration plant at a new plot at the facility.

   As such a cooling-project can be quite comprehensive and will include different disciplines and engineering works to plan and include in the investment estimates

   During the early phases, the expected scope of the project shall be described to make it clear for all relevant parties which works that are underway.

3. **Which cooling demand is to be covered (MW)?**

   A careful mapping shall take place to lock present and future capacity needs for cooling at the facility, i.e. do decide what should be the rated capacity for the cooling solution.

   The installation might replace an existing cooling installation with well-known capacity, but a detailed survey of cooling demands to cover now and in the future should be established and described in a memo.

   This is not only an exercise to collect data about present and future heat demands, but also to investigate energy saving opportunities described in section 1, by example introducing new temperature levels

4. **Which technology and refrigerant to use?**

   There are multiple technologies and refrigerant to chose between when selecting a solution. These will greatly impact the overall environmental footprint of the project.

   In point one the purpose was found, and now it is time to use it to go through the choices described in section 2. Use the purpose to chose between, GWP, ODP, safety, legislation, etc.

   Perhaps the purpose and scope cannot give clear answers to all the choices, and it that case, describe the different solutions left and bring to the discission makers.

A pre-feasibility report shall describe the purpose of the project, the design basis for the project and expected investments (CAPEX) and expected operation costs (OPEX) should be assessed for each alternative solution identified.

As such, the pre-feasibility report shall describe the business case for the project including relevant alternative solutions. The business case shall include an assessment of Total Cost of Ownership (TCO) for alternative solutions calculated as NPV.

The report shall be presented for the management in the company to decide on further steps, and often it should also be recommended also to initiate a dialogue with the bank regarding financing options for alternative solutions. Some banks will have attractive loan and financing options for sustainable solutions, which should be identified already in the early stages of the project development as this can have significant impact on financing costs etc.

Based on meetings with the management, further steps should be concluded. The scope of the project shall be described in a concluding memo and the feasibility phase initiated.

3.2 Feasibility phase

The aim of the feasibility phase is to carry out a pre-liminary solution design for the preferred solution and make a fairly accurate investment budget (CAPEX and OPEX) so as the management of the company can allocate funds for implementing the project.

Input and knowledge of vendors are important and beneficial when carrying out the feasibility study and can also give new inspiration to the configuration of the refrigeration plant and the preferred solutions. Further, vendors can assist with more accurate budget prices.

The feasibility study and following the Feasibility report must include all considerations necessary to achieve at the most optimal solution and may include topics such as:

- Project scope
- Detailed description of the project
- Refrigerant (temperature level), what is required at the consuming equipment
- The refrigerant also taking GWP and ODP in consideration
- Optimization of total cost of ownership (TCO) over a ten-year period
- Financial analysis, i.e. investment and operation costs (CAPEX and OPEX)
- Financing options
- Assessment of impacts on the operations of the enterprise
- Assessment of other impacts
- Project risks
- Overview of approvals and legislative framework
- Time schedule for implementation
- Project organization incl. preferred suppliers
- Recommendations on further steps

The outcome of the feasibility study is a report to be used as basis for the management's decision on the investment.

The feasibility study shall – in case the company needs bank financing – be presented to relevant banks to learn about relevant financing options to present for the management as part of the CAPEX-approval.

Finally, the feasibility study shall be presented to the management to get approval of funds for the investments (CAPEX).

3.3 Tendering phase

Based on the feasibility study and approval of CAPEX from the management, the detailed project preparation will comprise a number of phases.

3.3.1 Final scope definition

The exact scope of the contract must be established, and the following items will usually be included:

- Complete refrigeration plant incl. various auxiliary equipment
- Connection to existing refrigeration loop
- Connection to existing feed water supply incl. new feeding pumps
- Electrical connection
- Control system (interface to current control system)
- Delivery and assembly
- Insulation and panel cladding
- Platforms and stairs incl. connection to existing facilities
- Commissioning (in close cooperation with the owner)
- SAT, Site Acceptance Test
- Trial operation
- Documentation
- Necessary installation approval
- Noise measurement (If not done by the owner)
- Spare parts (option)

Depending on the circumstances auxiliary equipment can also be required like:

- Distribution systems (also in the production)
- Water treatment
- Building

The list above is highly depended on the actual project being performed since there are great variations in cooling projects.

3.3.2 Technical specifications

The requirements to equipment must be described unambiguously. It is particularly important to describe the overall delivery performance:

Environmental:

- Noise requirements

Functionality:

- Definition of the refrigerant
- Unmanned operation, for how long time
- Output (MW) (and minimum load)
- Pressure / temperature
- Max electrical consumption (at 100% load). Specify exactly what equipment is included.
- Total COP (at 100% load)
- Uptime

Definition of how the performance test shall be conducted. It is important to be very specific to avoid discussion on methods, timing, sampling, calculation afterwards.

It shall also be described how deviations shall be handled and what shall be fulfilled before a handover can take place.

3.3.3 Performance guarantees

Before setting the conditions for the performance guarantees it is important to evaluate the operation conditions to make sure that it is possible to make the test runs.

For refrigeration plants it can be a complex matter to specify parameters for the test since most parameters can vary a great deal over short time spans, e.g. outside temperature, load, temperature differences, need for defrosting, split between pressure levels.

It is therefore suggested to specify how the performance would changes when these parameters variate and specify a range of variation for the test to be acceptable.

3.3.4 Service contract

Taken spare parts and service of the plant into the contract will result in a fair price for the operation in the coming years. Also be aware on respond time, physical placement of resources and spare parts.

3.4 Contracting phase

The quotation evaluation has two main purposes:

- Identifying deviations from the tender documents
- Making the tenders comparable enabling price negotiations

In the technical clarification it is important to take a deep dive in the two most attractive quotations to ensure that there are not misunderstanding and deviations from the tender documents which are not immediately apparent.

After this clarifying and final price negotiation a contract can be completed.

3.5 Later project phases

It is important to following the installation and commissioning phase closely to monitor whether important design decisions in the feasibility and tendering phase are followed through

References

[1] Cooling Best Practices. Advancements in Free-Cooling Keep Breweries Cool Year-round.
https://coolingbestpractices.com/industries/beverage/advancements-free-cooling-keep-breweries-cool-year-round
Accessed 11-01-2024

[2] Zach Ellis. Picture of flooded evaporator with drop leg.
https://www.linkedin.com/posts/edmundyoong_alfalaval-industrialrefrigeration-alfacool-activity-6915562007425421312-4M6V/?originalSubdomain=my
Accessed 18-01-2024

[3] JMP. Cooling Tower and Condenser Water Design Part 1: The Refrigeration Cycle.
https://jmpcoblog.com/hvac-blog/cooling-tower-and-condenser-water-design-part-1-the-refrigeration-cycle
Accessed 17-01-2024

[4] Videncenter for klimavenlige kølemidler. Udfordringer ved kølemidler.
http://xn--klemidler-l8a.dk/om-koelemidler/miljoeeffekt-af-koelemidler/
Accessed 09-01-2024

[5] ScienceDirect. Ozone Depletion Potential.
https://www.sciencedirect.com/topics/engineering/ozone-depletion-potential
Accessed 09-01-2024

[6] UN ozone secretariat. Montreal Protocol.
https://ozone.unep.org/treaties/montreal-protocol
Accessed 09-01-2024

[7] NRDC. Phasing Down HFCs
https://www.nrdc.org/resources/phasing-down-hfcs
Accessed 09-01-2024

[8] Science direct. Kyoto Protocol.
https://www.sciencedirect.com/topics/earth-and-planetary-sciences/kyoto-protocol#:~:text=The%20Kyoto%20Protocol%20specifies%20that,of%20U.S.%20GWP%2Dweighted%20emissions.
Accessed 09-01-2024

[9] GEA. It’s time to change – Protect our future.
https://www.gea.com/en/articles/natural-refrigerants/index.jsp
Accessed 09-01-2024

[10] ICS Cool Energy. Industrial chiller refrigerants.
https://www.icscoolenergy.com/industrial-chiller-refrigerants/
Accessed 09-01-2024

[11] HPACEnineering. Retrofit or Replace: Considerations to Make When Changing Refrigerants
https://www.hpac.com/air-conditioning/article/20929980/retrofit-or-replace-considerations-to-make-when-changing-refrigerants
Accessed 09-01-2024

[12] EPA. Refrigerant Safety.
https://www.epa.gov/snap/refrigerant-safety
Accessed 09-01-2024

[13] University of Wisconsin Green Bay. Refrigerator.
https://blog.uwgb.edu/chem320c/refrigerator/
Accessed 11-01-2024

[14] IIT Kharagpur. Multi-Stage Vapour Compression Refrigeration Systems.
https://akashlangde.files.wordpress.com/2018/01/lecture-12-multi-stage-vapour-compression-refrigeration-systems.pdf
Accessed 11-01-2024

[15] Chegg.
https://www.chegg.com/homework-help/questions-and-answers/two-stage-ammonia-system-using-flash-gas-removal-intercooling-operates-cycle-shown-fig-1-c-q40494852
Accessed 11-01-2024

[16] SWEP. Economizer.
https://www.swep.net/refrigerant-handbook/10.-systems/asdf4/#:~:text=An%20economizer%20is%20a%20type,at%20an%20intermediate%20pressure%20level.
Accessed 11-01-2024

[17] Miljøstyrelsen. CO2 som kølemiddel i varmepumper
https://www2.mst.dk/udgiv/publikationer/2001/87-7944-330-3/pdf/87-7944-387-7.pdf
Accessed 11-01-2024

Annex 1. Selected suppliers of refrigeration solutions

Below an overview of national and international suppliers able to deliver BAT-solutions for industrial cooling in Vietnam is provided.

No.	Company name	Address of factory	Website	Refrigeration type
Domestic suppliers				
1	PHAN BACH REFRIGERATION TECHNOLOGY JOINT STOCK COMPANY	2nd Floor, Phuong Tower, 31C Ly Tu Trong, District 1, Ho Chi Minh City, Vietnam	https://www.phanbach.vn/	Industrial Refrigeration
2	ASIA REFRIGERATION INDUSTRY JOINT STOCK COMPANY	Lot 25-27, Central Street, Tan Tao Industrial Park, Tan Tao A Ward, Binh Tan District, Ho Chi Minh City, Vietnam	https://arico.com.vn/trang-chu/	Food Processing
3	SEAREE REFRIGERATION ELECTRICAL ENGINEERING CORPORATION	1st Floor, Helicopter Building, Airport Area, Nguyen Van Linh Street, Danang City, Vietnam	https://searee.com/	M&E, Industrial Refrigeration
4	HUNG TRI REFRIGERATION INDUSTRY JOINT STOCK COMPANY	51 Tran Phu, Ward 4, District 5, City. Ho Chi Minh, Vietnam	https://hungtri.com/	Seafood Processing, Cold Storage, M&E
5	R.E.E MECHANICAL & ELECTRICAL ENGINEERING JOINT STOCK COMPANY	2nd Floor, Etown 5, 364 Cong Hoa Street, Ward 13, Tan Binh District, Ho Chi Minh City	https://www.reeme.com.vn/	M&E, Industrial Refrigeration
6	HAWEE MECHANICAL AND ELECTRICAL JOINT STOCK COMPANY	Hawee Building, Lot D2 - Land use rights auction area, Van Phuc ward, Ha Dong district, Hanoi City	https://me.hawee.com.vn/	M&E, Industrial Refrigeration
7	SIGMA ENGINEERING JOINT STOCK COMPANY	Floor 27, Building A, HUDTOWER Building, No. 37 Le Van Luong, Nhan Chinh Ward, Thanh Xuan District, Hanoi City, Vietnam	http://sigma.net.vn/en/	M&E, Industrial Refrigeration

8	NAM THINH MECHANICAL ELECTRICAL REFRIGERATION CORPORATION	8-10, Nguyen Ba Tuyen, Ward 12, Tan Binh District, Ho Chi Minh City, Vietnam	http://namthinh.com.vn/	M&E, Industrial Refrigeration
9	SAVA M.E JOINT STOCK COMPANY	168/75 Nguyen Gia Tri, Ward 25, Binh Thanh District, Ho Chi Minh City, Vietnam	https://www.savame.com/	M&E, Industrial Refrigeration
10	BACH KHOA EQUIPMENT INTERNATIONAL JOINT STOCK COMPANY	729 Ba Thang Hai Street, Ward 06, District 10, Ho Chi Minh City, Vietnam	https://bkic.vn/	Industrial Refrigeration
11	TST CO., LTD	307/33 Nguyen Van Troi, Ward 1, Tan Binh District, Ho Chi Minh City, Vietnam	https://tst-vn.com/	Seafood Processing, Cold Storage, Industrial Refrigeration
12	TAN LONG MECHANIC ELECTRIC REFRIGERATION JOINT STOCK COMPANY	86 Dong Den, Ward 14, Tan Binh District, Ho Chi Minh City, Vietnam	https://tanlongvn.com/	Seafood Processing, Cold Storage, Industrial Refrigeration
13	THIEN PHUC REFRIGERATION CO.,LTD	38 Hoa Cuc Street, Ward 07, Phu Nhuan District, Ho Chi Minh City, Vietnam	https://thienphuc.asia/	Seafood Processing, Cold Storage, Industrial Refrigeration
14	TRUONG PHAT TRADING AND SERVICE TECHNICAL REFRIGERATION ELECTRIC COMPANY LIMITED	16/13F Hamlet 5, Vinh Loc B Commune, Binh Chanh District, Ho Chi Minh City, Vietnam	https://dienlanhtruongphat.vn/	Seafood Processing, Cold Storage, Industrial Refrigeration
15	VIET TRADING ELECTRICITY REFRIGERATION INSTALLATION ENGINEERING COMPANY LIMITED	400 Nguyen Thi Thap Street, Ward Tan Quy, District 7, Ho Chi Minh City, Vietnam	https://veevn.com/	Cold Storage, Industrial Refrigeration

16	WESTERN REFRIGERATION ELECTRIC COMPANY LIMITED	28 An Hoi Street, Ward 13, Go Vap District, Ho Chi Minh City, Vietnam	https://westernvn.com/vi/	Seafood Processing, Cold Storage, Industrial Refrigeration
17	Eka-Kool Vietnam Ltd Auviet Ltd.	94/30 Hoa Binh Str, Ward 5, District 11, HCMC, Vietnam	https://eka-kool.com/	Industrial Refrigeration
International suppliers				
1	COOL PARTNERS ApS	Bøgekildevej 21, 8361 Hasselager, Denmark	https://coolpartners.dk	Industrial Refrigeration
2	GEA VIETNAM COMPANY LIMITED	10th Floor, No. 198 Nguyen Thi Minh Khai Street, Vo Thi Sau Ward, District 3, Ho Chi Minh City, Vietnam	https://www.gea.com/	Industrial Refrigeration
3	Gotek Vietnam Company Limited	127/10 Hoang Dieu 2 street, Linh Trung ward, Thu Duc district, HCMC.	http://www.gotek.com.vn/	Industrial Refrigeration
4	Danfoss Vietnam Company Limited	Room 10.2, Floor 10, E-Town1, No. 364 Cong Hoa - Ward 13 - Tan Binh District - Ho Chi Minh City.	https://www.danfoss.com/en/	Industrial Refrigeration
5	Alfa Laval Vietnam Liability Limited Company	3rd Floor, Petroland Tower, 12 Tan Trao St., District. 7,Ho Chi Minh City	https://www.alfalaval.sg/	Industrial Refrigeration
6	GUNTNER ASIA PACIFIC PTE. LTD.(SINGAPORE)	207-208 Lots CR3-6, CR3-7, Tan Phu Ward, District 7, Ho Chi Minh City	https://guntner.com/	Industrial Refrigeration
7	MAYEKAWA VIETNAM COMPANY LIMITED (MYCOM)	Room 305, 3rd floor, Tuoi Tre Building, 60A Hoang Van Thu,	http://mycomvietnam.com/	Seafood Processing

		Ward 9, Phu Nhuan District, HCMC		
8	BITZER REFRIGERATION ASIA REPRESENTATIVE OFFICE PTE. LTD. IN HO CHI MINH CITY	Room 504C, 5th Floor, CentecTower, 72-74 Nguyen Thi Minh Khai Street - Vo Thi Sau Ward - District 3 - Ho Chi Minh City.	https://www.bitzer.de/us/us/	Industrial Refrigeration
9	JOHNSON CONTROLS-HITACHI AIR CONDITIONING VIETNAM LIMITED LIABILITY COMPANY	6th Floor, Tower B, Royal Center, 235 Nguyen Van Cu, Nguyen Cu Trinh Ward, District 1, Ho Chi Minh City, Vietnam		Industrial Refrigeration
10	TRANE VIETNAM SERVICES COMPANY LIMITED	Unit 901-903, 9th Floor, CentrePoint Office Building, No. 106, Nguyen Van Troi Street, Ward 08, Phu Nhuan District, Ho Chi Minh City, Vietnam	https://www.trane.com/commercial/asia-pacific/vn/vi/Trane%20Vietnam/locate-sales-offices/HoChiMinhOffice.html	Industrial Air Conditioning
11	CARRIER VIETNAM AIR CONDITIONING COMPANY LIMITED	Room 1101, 11th Floor, Centre Point Building, 106 Nguyen Van Troi, Ward 08, Phu Nhuan District, Ho Chi Minh City	-	Industrial Air Conditioning
12	AU VIET CO, LTD.,	94/30 Hoa Binh, Ward 5, District 11, HCMC	https://auvietco.com/	Industrial Refrigeration
13	MY HAO INTERNATIONAL TRADING COMPANY LIMITED	79/13 Pham Thai Buong, Phu My Hung Quarter, Tan Phong Ward, District 7, Ho Chi Minh City, Vietnam	https://www.luwa.com	Industrial Air Conditioning