[APPLICATION NOTE #191]

Chiller Plants - Best Design Practices

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- **Noise impact:** Noise propagation, typologies of noise fields, impact of the distance and correct evaluation at different noise pressure positions
- **Electrical Circuit**: Main concepts on electrical data and components, redundancy options and compressor starting procedures

Designing a plant is always a challenge that involves different scopes, issues and opportunities for the designer. The main goal of this document is to provide some recommendations, best practices and typical solutions that can help as a guide to make good design choices.
As designing is a sort of art and any engineer has his or her own style and ideas, the following pages do not represent a reference design, but rather suggestions and best practices.

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1. Outdoor temperature operation

Outdoor temperatures can significantly influence the proper operation and reliability of chillers. Air-cooled and free-cooling versions are particularly influenced, while water-cooled versions are more stable because they are installed indoor. According to the installation conditions, some guidelines for unit selection and configuration should be considered. These are addressed in the following sections.

1.1 Low outdoor temperature operation

When a chiller is designed to operate mainly at low outdoor temperatures, a specific configuration is to be selected:

- Free-cooling version or “low outdoor temperature” option is required.
- Antifreeze mixtures are mandatory for free-cooling chillers, while free-cooling chillers with a glycol-free option or chillers and heat pumps configured with antifreeze heaters may be used with pure water.
- The local display interface onboard the unit is an LCD terminal and, therefore, when external temperatures are very low, the visualization may be temporarily interrupted. This does not damage the terminal, but rather limits maintenance operations. A good practice is to install a remote display interface, internally installed, for chillers installed in low outdoor temperatures areas.

1.2 Very low outdoor temperature operation

When a chiller is designed to operate in areas where the Outdoor temperatures could be very low, i.e. lower than -25°C, additional recommendations and configurations are necessary.

The unit has to be specifically designed for such outdoor temperatures and some options may not be available. In particular, it is necessary to provide a separate, always active, 230/1/50 power supply for the following components:

- Anti-condensation heater in the electrical board
- Pumps heaters
- Heater for internal piping
- Heater for the evaporator
- Fan regulators or EC motors that are enhanced and fitted with integrated heater
- Dedicated control software (integrated in the main board) that protects the fans at low-temperature operation or in case of heavy snow
- Expansion vessels (Note: Water tanks are recommended to be installed outside the unit in a separate and closed room.)
- Remote display interface

1.3 High outdoor temperature operation

Although units are designed for high outdoor temperature operation, a continuous operation close to high outdoor temperatures limits may stress the unit. Some additional measures should be adopted on site.

- Continuous power supply ensures electrical board ventilation, improving the overall unit reliability. Therefore, it is recommended not to switch-off the unit on site.
- Chiller orientation and position should be carefully evaluated to reduce the thermal stress for electrical components.
- A remote display interface is suggested to monitor the unit when outdoor conditions are not suitable for a direct visit of the unit.

2. Location requirements

Outdoor HVAC equipment must be located so as to minimize noise and vibration transmission to the occupied spaces of the building structure it serves. Moreover, a careful design of the area around the chiller must be carried-out in order to limit any influence of the external environment on the unit's performance in terms of noise, vibrations, cooling capacity, efficiency, operation and reliability.

2.1 Noise considerations

If the equipment must be located close to a building, it should be placed next to an unoccupied space such as a storage room, mechanical room, etc. It is not recommended to locate the equipment near occupied, sound sensitive areas of the building or near windows. Locating the equipment away from structures will also prevent sound reflection and refraction, which can increase the perceived noise levels at property lines, or other sensitive points.

When physically isolating the unit from structures, it is suggested to avoid using rigid supports, and any metal-to-metal or hard material contact when possible. This includes replacing spring or metal weave isolators with elastomeric isolators.

- Refer to product specification document for noise ratings
- Locate the unit away from sound-sensitive areas
- Install the optional elastomeric isolators under the unit
- Chilled water piping should not be supported by chiller frame
- Install rubber vibration isolators in all water piping
- Seal all wall penetrations

Note: Consult an acoustical engineer for critical applications.
See dedicated section for further details.

2.2 Foundation

Provide rigid, non-warping, mounting pads or a concrete foundation of sufficient strength and mass to support the operating weight (i.e., including completed piping, and full operating charges of refrigerant, oil and water).
Refer to the unit dimensions/weights documents for unit operating weights.
Once in place, the unit must be level (max 6 mm each meter) over its length and width.

2.3 Clearances

Provide enough space around the unit to allow the installation and maintenance personnel unrestricted access to all service points. Refer to submittal drawings for the unit dimensions, to provide sufficient clearance for the opening of control panel doors and unit service. Refer to the unit dimensions/weights document for minimum clearances.
In all cases, local codes that require additional clearances will take precedence over these recommendations.

Pic 2.1

- **Walled enclosure installations**

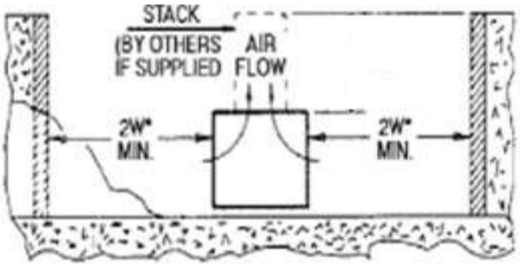
  When the unit is placed in an enclosure, small depression, or simply close to walls, the top of the surrounding walls should be no higher than the top of the fans. The chiller should be completely open above the fan deck. There should be no roof or structure covering the top of the chiller.
- **Multiple units**

  It is necessary to prevent air recirculation between the air discharged and the suction in the condenser.
  Moreover, when multiple chillers are installed close to each other in the same area or with sides close to walls, it is important to evaluate the airflow through the unit in order to guarantee air recirculation.
  In some cases, chimneys should be installed on the top of the unit as shown in Pic. 2.1.

Units in pits

The top of the unit should be the same level as the top of the pit, and its distance from each side should be twice the minimum clearances required in the installation drawings.

If the top of the unit is not at the same level as the top of the pit, discharge chimneys should be used to raise the discharge air to the top of the pit, evaluating the max allowed pressure drop for the discharge fans. This is a minimum requirement.



Pic 2.2

Polluted, costal or industrial installations

When outdoor air quality is affected by an aggressive an atmosphere as in coastal regions, polluted areas, or industrial districts, condensing and free-cooling coils treatments are recommended.

Several protection treatments for coils are available. The best choice depends on air characteristics, unit conditions and required maintenance programs.

The following are usual available solutions:

- Pre-painted aluminum fins, which protects the surface of coil fins, but it does not cover the fin sections and coil frame
- Electrochemical treatments such as cataphoresis, which completely protects coils (fins and frame), covering the external surface
- Protective paint, which completely protect coil fins, covering the external surface
- Copper fins coils, which replace aluminum with copper and reduce the corrosion effect but features a lower thermal exchange coefficient

Corrosion resistance

- Pre-painted aluminum fins: Salt-spray test according to specification ASTM B 117-73 (5% sodium chloride concentration, 360 hours). The heat exchanger with copper tube and pre-painted aluminum fins has performance similar to a copper-copper solution.
- Cataphoresis treatment: With this treatment, resistance in a salty fog chamber (ASTM B117) of up to 500 - 700 hours can be reached
- Protective paint: It depends on the paint features; usually corrosion resistance can be considered similar to cataphoresis.
- Copper finned coil with tinning treatment: With this treatment, resistance in a salty fog chamber (ASTM B117) of up to 500 - 800 hours can be reached. Note: the average thickness of the tinning treatment is 3 - 4 micron.

Performance influence

- Pre-painted aluminum fins: According to the unit technical details and the operating conditions, this treatment could change the performance of the unit in terms of cooling capacity, absorbed power, air flow and maximum ambient temperature limits. Thus, these values could be different from that of the unit equipped with standard coils.
- Cataphoresis treatment: This treatment could slightly change the performance of the unit in terms of air flow and consequent max ambient temperature limits. Thus, these values could be different from that of the unit equipped with standard coils.
- Protective paint: It depends on the painting features, usually performance influence can be considered similar to Cataphoresis.
- Copper finned coil with tinning treatment: This treatment could change the performance of the unit in terms of air flow and consequent maximum ambient temperature limits. Thus, these values could be different from that of the unit equipped with standard coils.

The best choice depends on application features and outdoor conditions, which must be evaluated carefully. Protection treatments improve chiller reliability level but may adversely affect unit performance depending on operating conditions.

Furthermore, when installations are affected by dust or volatile object compounds, it is suggested to install air filers to protect coils. This solution protects coils from accidental contact and can be considered best practice for on-site safety.

3. Hydraulic circuits

3.1 Main hydraulic components

The following recommendations do not represent a reference design, but good practices for installations and site design.

Protection installed outside the units

In order to protect and to allow excessive maintenance, chillers should be installed with the following:

- **Water filter / Strainers**: To prevent residue and metallic burrs from seriously damaging the refrigeration components, install a metallic water filter in the refrigerant inlet pipe. A typical suggested mesh is 22.86 or 25 according to the French number.

Suggested water filter features

- **French number 25**
- **Mesh 22.9**
- **Nit 45**

Wire diameter mm	Mesh opening mm	Open area %
0.24	0.87	61.3

Table 3.1

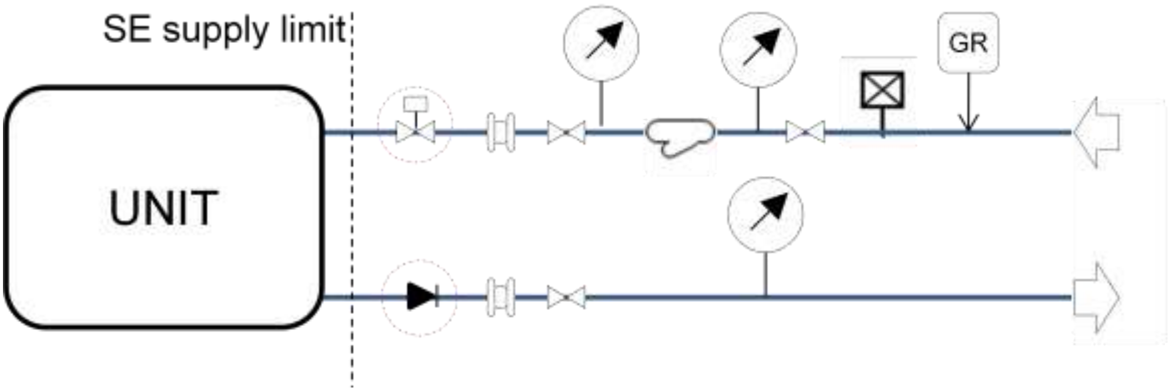
- The filter is usually provided by the main contractor. Install pressure gauges before and after the strainer. This will make it easy to see when the strainer needs cleaning.
- **Shut-off valves**: It must be possible to isolate the inlet/outlet water connections of the unit. For this reason, shut-off valves must be installed on external piping.
- **Elastic coupling / compensators**: In order to prevent vibration propagation, elastic compensators are usually installed to decouple the unit and the general piping.
- **Piping supports** are necessary to sustain any connections to and from the unit.
- **Automatic air valves** (air bleed) must be installed in the external circuit to remove air from the water circuit.
- **Water drainage system** must be externally installed to remove water, if necessary.
- **Balancing valve** must be installed to balance the water pressures into the circuit.
- **Refilling system** is necessary on the suction side of the unit at minimum setting 1.5 bar.
- **Safety valves and expansion vessel** for units without pumps.
- **Water gauges** on in/outlet piping both for commissioning and maintenance program.
- **By-pass line**: A minimim flow must be guaranteed in any operational mode. A by-pass valve/arrangement must be provided in any case to avoid flow alarm. This is usually installed at the end of the pipe works.
- **No return valves** must be installed on outlet water piping if the unit is not fitted with onboard pump(s) or if it is fitted with one pump only.
- **Motorized 2-way valve**: If unit is not fitted with pump(s), it is mandatory to install a 2-way motorized valve in the suction side of each unit to prevent by-pass. If the unit is fitted with onboard pump(s) (1 or 1+1), it is strongly suggested to install the valve (refer to the following table for details).
- **Chiller start-up settings,** must be carefully evaluated when motorized valves and/or shut-off valves are installed to prevent that chiller/pump switch-on when water flow is not completely available.

Water circuit components		
Unit configuration	Motorized 2-way valve	Non-return valve
Without onboard pump/s	Mandatory	Mandatory
With 1 onboard pump	Strongly suggested*	Mandatory
With 2 onboard pumps	Strongly suggested*	Not necessary - Fitted onboard
With 1 VSD onboard pump	Suggested*	Mandatory
With 2 VSD onboard pumps	Suggested*	Not necessary - Fitted onboard

*The motorized 2-way valve isolates the unit stand-by when it does not operate. On units fitted with onboard pump/s, this is not necessary if the pump head pressure is in line with the circuit pressure drop. In the event of extra head pressure compared to the pressure drop, recirculation may happen through the stand-by unit/s. A motorized 2-way valve prevents this issue. Of course, VSD pump/s mitigate this situation.

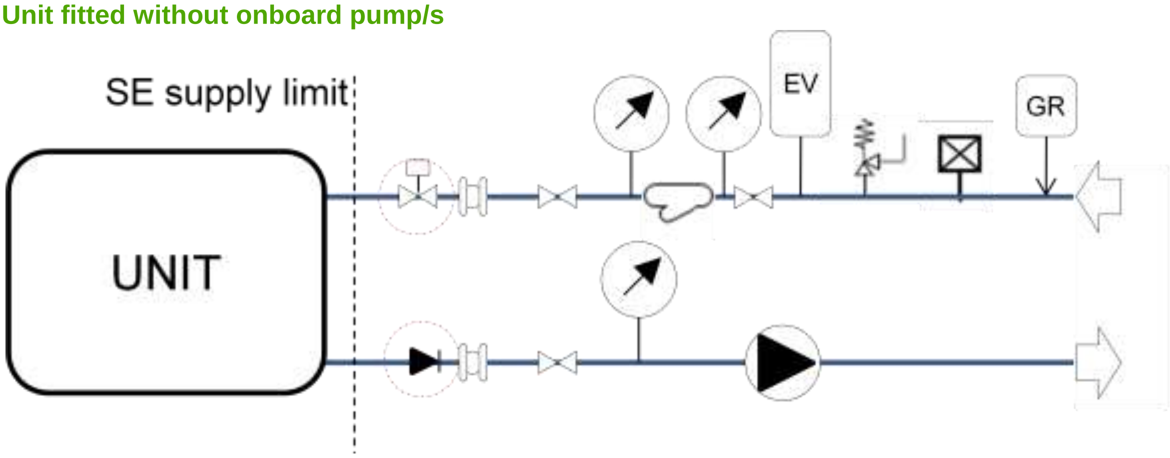
Table 3.2

Unit fitted with onboard pump/s



Pic. 3.1

Unit fitted without onboard pump/s



Pic. 3.2

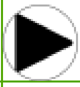
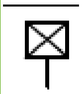
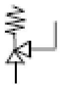
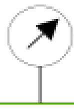
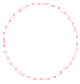
Main components							
EV	Expansion vessel		Pump		Elastic compensator		Strainer / filter
GR	Filling system with backflow protection		Air valve		Safety valve		Pressure gauge
	To be fitted or not per the table above		Shut-off valve		Motorized valve		No-return valve

Table 3.3

3.2 Intelligent free cooling hydraulic design recommendations

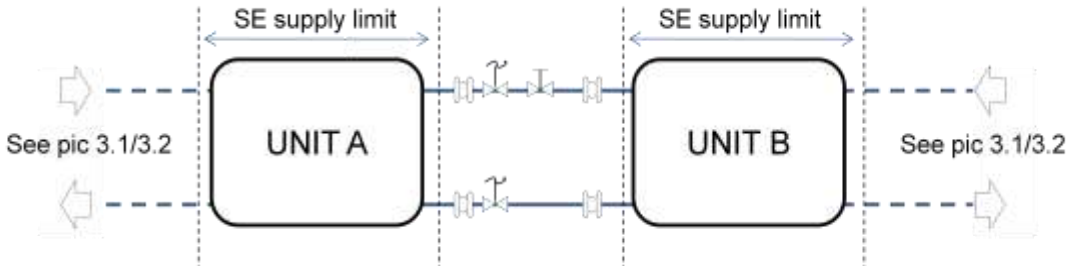
In addition to the recommendations above, the following notes must be applied on units equipped with intelligent free-cooling.

- **Pipe works sizing**: While external piping connected to the unit can be designed with the same diameter as the unit's intelligent free-cooling connections, the common manifold must be designed in order to keep the same water velocity. For example, when two units are installed, the diameter for the common manifold has to be calculated with a factor 1.44x, i.e. the IFC connections x 1.44.
- **Balancing valve** must be installed on the intelligent free-cooling manifolds to balance the water pressures into the circuit.
- **Shut-off valves** must be installed externally to isolate the intelligent free-cooling connections of the unit. For this reason manual shut-off valves must be installed on external pipe works
- **Elastic compensators** are usually installed to prevent vibration propagation by decoupling the unit and the intelligent free-cooling piping.

Water circuit components with Intelligent free-cooling		
Unit configuration	**Motorized 2-way valve***	**Non return valve***
Without onboard pump/s	Mandatory	Mandatory
With 1 onboard pump	Strongly suggested**	Mandatory
With 2 onboard pumps	Strongly suggested**	Not necessary- Fitted onboard
With 1 VSD onboard pump	Suggested*	Mandatory
With 2 VSD onboard pumps	Suggested*	Not necessary- Fitted onboard

* Refer to the pictures 3.2 for details
**The motorized 2-way valve isolates the stand-by unit when it does not operate. On units fitted with onboard pump/s, this is not necessary if the pump head pressure is in line with the circuit pressure drop. In the event of extra head pressure compared to the pressure drop, recirculation may happen through the stand-by unit/s too. A motorized 2-way valve can prevent this issue. Of course VSD pump/s mitigate this situation.

Table 3.4



Pic. 3.3

Main components					
	Shut-off valve		compensation valve		Elastic compensator

Table 3.5

3.3 Pump(s) selection

One of the most critical items in designing a chilled water plant is the evaluation and calculation of hydraulic features. In particular, pumps must be selected in order to match available head pressure with system pressure drop values.
Since these values depend on operating conditions, water temperatures, glycol percentage, hydraulic devices, piping sizes, final layout, and many other factors, the support of mechanical consultants is generally required.
An incorrect match between pumps and pressure drop creates unbalanced head pressure. This changes the water flow, which has a direct influence on performance, pump reliability, operation, and availability of the units (Chillers and CRACs or Close-Coupled units).

The main consequences of an incorrect hydraulic balancing are:

- Performance: Water flow influences water velocity and deltaT between chiller-side inlet and outlet water. Speed influences the capability to exchange the thermal load into the chiller. DeltaT influences the operative conditions for compressors.
- Reliability: Water flow influences both pump and unit operation. Too high water flow values increase pump motor amperage, which can generate a pump protection alarm intervention with a consequent critical alarm on the unit. Water flow that is too low can cause a flow alarm (anti-freeze evaporator protection). Both alarms force the unit to stop.
- Operation: Water flow that is too high influences the precision of the chiller water temperature, with the consequence being not-optimized operation of the Chillers and CRACs or Close-Coupled units.
- Availability: High water-flow speed could damage the evaporator if any debris is in the water circuit.

Proper pump selection is required in order to ensure correct site operation.
The chillers and air-conditioner manufacturers, as device providers do not own the complete overview and responsibility of the plant.
The consultant, based on all the information provided by the component manufacturers (provided by the chiller manufacturer and by the installer/contractor), is responsible for the correct matching between the unit and the system. The consultant should then check these values and verify they match with the system.
Correct calculation of the pressure drop of the system is complex and, therefore, should be carried-out by whomever has the responsibility of the design.

In order to aid in the correct matching between pumps and plant, the following procedure is recommended. Of course, the final decision and responsibility is owned by the consultant.

- Check the circuit typology and follow the suggestions below.
- Evaluate the circuit pressure drop at different configurations and working conditions.
- Check that the circuit pressure drop matches with the available head pressure reported in the chiller datasheet.

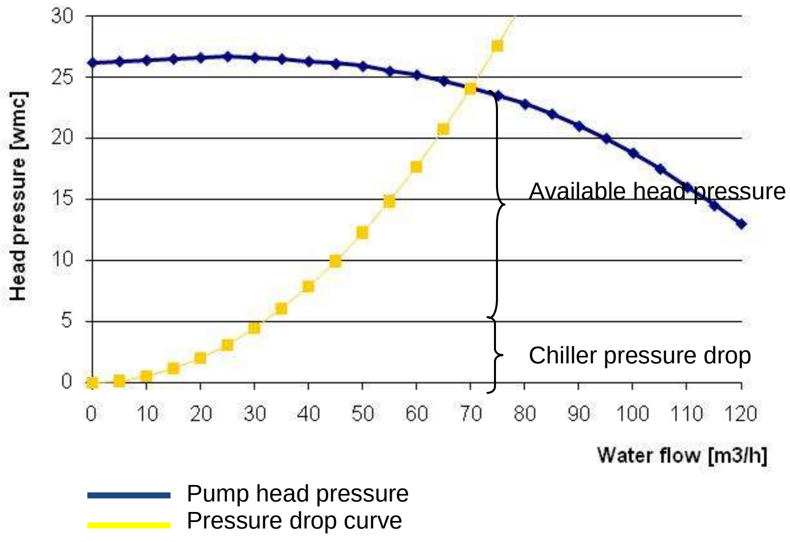
Circuit typology

- Primary / secondary
  - If the circuit is primary / secondary, the required available head pressure of the pumps installed onboard or close to the chillers is usually low[1].
  - If the circuit is primary / secondary, it is important to evaluate the site conditions, i.e.
    a. If the site configuration is the final configuration, fixed speed pumps are sufficient.
    b. If the site configuration is the final configuration, VSD pumps allow to set the correct head pressure on site and to (at least partially) prevent incorrect installations.
    c. If the site configuration is not the final configuration, VSD pumps are strongly recommended.
- Primary only
  - If the circuit is a primary only, the required available head pressure of pumps installed onboard or close to the chillers is usually high[1].
  - If the circuit is a primary only, it is important to evaluate the internal units, i.e.
    a. 2-way valves
       - VSD pumps are required together with a continuous control of the ΔP / head pressure. Note that both the minimum and maximum pressure have to be considered.
       - Balancing valves are recommended.
       - An overpressure valve must be installed on the final edge of the circuit to prevent water flow alarm in the event of closed valves. This situation must be considered during the design phase and it can be solved with discharge valves and/or controlled motorized valves to be installed not only at the final edge.
    b. 3-way valves
       - Fixed speed pumps are enough.
       - Balancing valves are required.
       - Overpressure bypass valve should be installed at the final edge of the circuit if the pressure drop of the 3-way valve bypass line is quite high. This is necessary to prevent a water flow alarm in the event of by-passed valves.
    c. 3-way valves with future expansions
       - VSD pumps are required.
       - Balancing valves are required.
       - An overpressure valve must be installed at the final edge of the circuit to prevent water flow alarm in the event of closed valves. This situation must be considered during the design phase, and it can be solved with discharge valves and/or controlled motorized valves to be installed not only at the final edge.

General notes and recommendations

The final evaluation for “high” and “low” values is the consultant’s responsibility. A typical values for “low” available head pressure is 50 kPa, while “high” usually means 150 kPa. These values are indicative only and they depend on the final layout of the circuit.
Note: With “available head pressure” at a certain water flow, it is usually meant that the head pressure of the pumps without the internal pressure drop of the chiller, i.e. $H_{available} = H_{pump} - pressure\ drop_{chiller}$

[1] The final evaluation for “high” and “low” values are the consultant’s responsibility. Typical values for “low” available head pressure is 50 kPa, while “high” usually means 150 kPa. Actual values depend on the final layout of the circuit.



Pic. 3.4

The pressure drop calculation depends on the following parameters:

- Circuit type and layout
- Load conditions
- Circuits or part of the circuits enabled/disabled
- Units, devices, pipe works features and pressure drops
- Water temperatures
- Antifreeze mixtures percentage (glycol)
- Antifreeze mixtures type (ethylenic / propylenic glycol. Note: Only these typologies are admitted by Schneider-Electric chillers and air-conditioners)
- Water filter clogging

NOTE: Best practices require the installation of balancing valves, overpressure valves, elastic compensators, motorized valves on the inlet side of the chillers, non return valves on the discharge sides of the chillers, and water filters close to the chillers. All these components must be considered in the circuit design and calculation.
VSD pump/s can operate between 30 to 50Hz; therefore, a minimum head pressure is provided. A by-pass valve / arrangement with a balancing valve must be provided to avoid flow alarm.

Usual relations are the following:

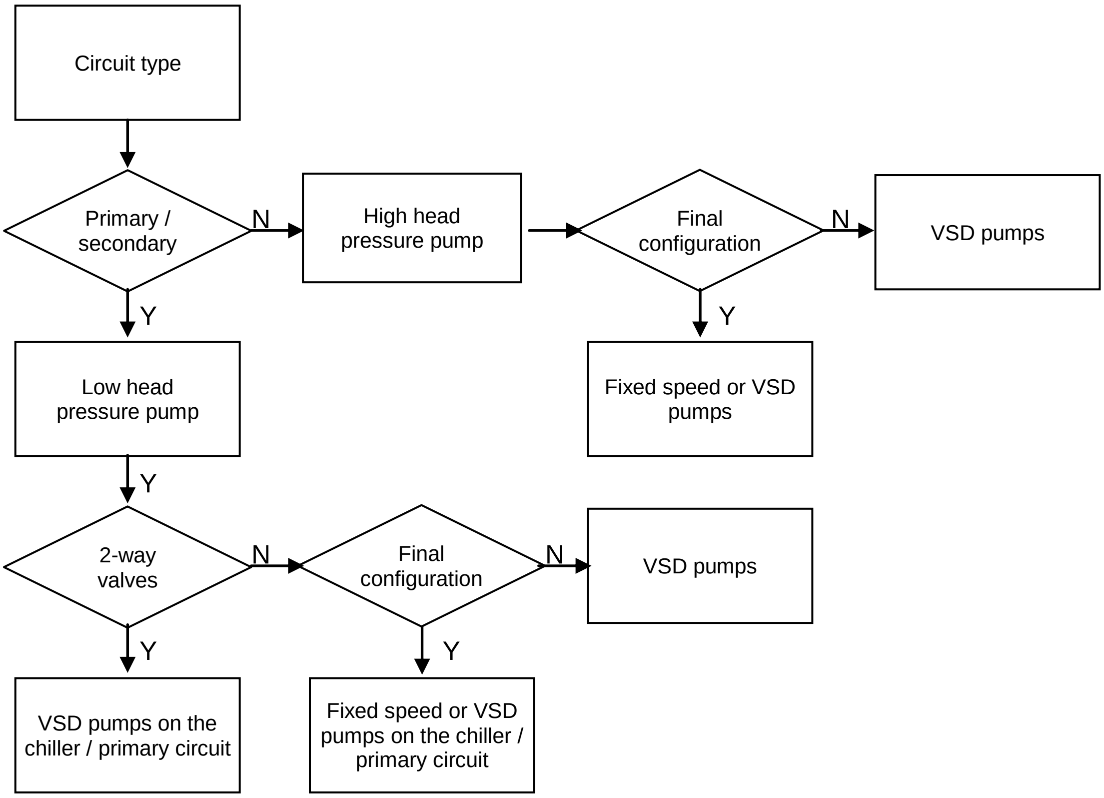
- Considering the same water flow

$$\left(\frac{\mathrm{Hz}_1}{\mathrm{Hz}_2}\right)^2 = \left(\frac{\text{Head pressure}_1}{\text{Head pressure}_2}\right) \quad (3.1)$$

- Considering the same head pressure

$$\frac{\mathrm{Hz}_1}{\mathrm{Hz}_2} = \left(\frac{\text{Water flow}_1}{\text{Water flow}_2}\right) \quad (3.2)$$

Circuit typology- quick guide



Pic. 3.5

3.4 Absorbed power on VSD pumps

Inverter driven pumps allow the motor rotation to adapt according to the inverter settings. As described in the operational logic section (flexible or auto-adaptive), it is possible to operate based on a fixed setting or an automatic operation on the difference in pressure between the IN/OUT section of the unit.
When the operating set-point is manual, it is possible to define the rotation speed for the pump and, consequently, to adjust the power consumption of the motor.

The cubed ratio between rotation speeds, is directly proportional to the ratio between absorbed power values in the two conditions, i.e. as follows, considering the motor efficiency (η).

$$\left(\frac{Hz_1}{Hz_2}\right)^3 \approx \left(\frac{P_{Hz_1}}{P_{Hz_2}}\right)\cdot\eta \xRightarrow{\text{passing from 50Hz to 30Hz}} \left(\frac{50}{30}\right)^3 \approx \left(\frac{P_{50}}{P_{30}}\right)\cdot\eta \Rightarrow P_{30} = \frac{P_{50}}{4{,}6}\cdot 1{,}1 \quad (3.3)$$

Therefore, for 50 to 30 Hz the pump power is reduced according to the following:

$$\left(\frac{50}{30}\right)^3 \approx \left(\frac{P_{50}}{P_{30}}\right) \rightarrow P_{30} = \frac{P_{50}}{4{,}6}\cdot 1{,}1 \quad (3.2)$$

Analyzing the pump head pressure, the ratio between head pressure values in two different conditions is proportional to the ratio between the speed values, elevated at square.
It is therefore possible to calculate the absorbed power at different head pressure conditions as per the following,

$$\left(\frac{\text{Head pressure}_1}{\text{Head pressure}_2}\right) \approx \left(\frac{Hz_1}{Hz_2}\right)^2 \rightarrow \sqrt{\frac{\text{Head pressure}_1}{\text{Head pressure}_2}} \approx \frac{Hz_1}{Hz_2} \rightarrow \left(\sqrt{\frac{\text{Head pressure}_1}{\text{Head pressure}_2}}\right)^3 \approx \left(\frac{P_{Hz_1}}{P_{Hz_2}}\right)\cdot\eta \quad (3.4)$$

Example. Considering a pump that provides a head pressure of 278 kPa at 2,3 kW, the absorbed power at 200 kPa is

$$P_{200} \approx \frac{P_{278kPa}}{\left(\frac{278}{200}\right)^{3/2}}\cdot 0{,}8 = \frac{2{,}3}{1{,}63}\cdot 1{,}1 \quad (3.5)$$

3.5 Water flow recommendations

Usual water flow limits

Water flow variation influences the operation of the unit. A water flow that is too high generates turbulence in the heat exchangers with consequent reduction in the heat exchange and very high pressure drop across the evaporator.
A water flow that is too low could cause laminar flow in the evaporator with consequent reduction in exchange capacity, freeze-up problems, scaling, stratification, and poor control.
These conditions would reduce the water side pressure drop up to the protection device set limits, generating a low water flow alarm, which would stop the unit and require a manual reset.

For this reason, the following limits are required on the nominal water flow:

- Minimum water flow: -40% than the nominal water flow
- Maximum water flow: +40% than the nominal water flow

Other specific operations could be possible on request

Suggested pressure drop values through the unit:

- Minimum: 10 kPa
- Maximum: High limits for head pressure must consider following recommendations:
  - 100 kPa normal operation
  - 150 kPa check pumps available head pressure
  - 150 kPa a specific evaporate may be necessary

Avoidance of short water loops

Adequate chilled water volume is an important system design parameter because it provides stable chilled water temperature control and helps limit short cycling of chiller compressors to improve general component reliability.
The chiller's temperature control sensors are located in the inlet and outlet water piping.
This location allows the building to act as a buffer to slow the rate of change of the system water temperature. If there is not a sufficient volume of water in the system to provide an adequate buffer, temperature control can suffer, resulting in erratic system operation and excessive compressor cycling.
Typically, a two-minute water loop circulation time is sufficient to prevent short water loop issues.
Therefore, as a guideline, ensure the volume of water in the chilled water loop equals or exceeds two times the evaporator flow rate.
For systems with a rapidly changing load profile, the amount of volume should be increased.
If the installed system volume does not meet the above recommendations, the following items should be given careful consideration to increase the volume of water in the system and, therefore, reduce the rate of change of the return water temperature.

- A volume buffer tank located in the outlet water piping.
- Larger system supply and return header piping (which also reduces system pressure drop and pump energy use).

Minimum water volume for a process application

If a chiller is attached to an on/off load such as a process load and if the system has only the minimum water volume recommended, it may be difficult for the controller to respond quickly enough to the very rapid change in return solution temperature. Such systems may cause chiller low temperature safety trips or even evaporator freezing. In this case, it may be necessary to add or increase the size of the mixing tank in the return line.

3.6 Water quality recommendations

Water quality is essential to ensure both performance and reliability. Below are the heat exchangers corrosion resistance tables. These tables provide a summary evaluation of the substances that could create corrosion problems. No guarantees can be deduced from this table due to the complex and carious chemical reactions involved in each particular situation.

Plate Heat exchangers

Material	Approximate Concentration area [mg/l]	Compatibility with Standard Heat Exchanger
pH-value	7 ÷ 9 (Value)	OK
Chloride Cl^-	< 50	OK
Free Chlorine Cl2	<0, 5	OK
Sulphate $SO4^{--}$	< 100	OK
Free Carbon Dioxide CO2	< 10 10 ÷ 50	OK *
$HCO3^-$ / $SO4^{--}$	> 1 (Value)	OK
Nitrate	< 100	OK
Hydrogen Sulphide H2S	< 0,05	OK
Oxygen O2	< 0,1 0,1 ÷ 2	OK*
Ammonium NH4 +	<0.5	OK
Phosphate PO4 3-	< 2	OK
Iron and Manganese Fe3+ / Mn++	< 0,5	OK
Depositable (organic) substances	0 (Value)	**
Hardness	4 ÷ 8.5dH	OK

Table 3.5

Shell and tubes and flooded heat exchangers

Material	Approximate Concentration area [mg/l]	Compatibility with Standard Heat Exchanger
pH-value	7 ÷ 9 (Value)	OK
Chloride Cl^-	< 3 3 ÷ 50	OK
Free Chlorine Cl2	<0, 5	OK
Sulphate $SO4^{--}$	< 50 50 ÷ 100	OK
Free Carbon Dioxide CO2	< 5 5 ÷ 50	OK *
$HCO3^-$ / $SO4^{--}$	> 1 (Value)	OK
Nitrate	< 100	OK
Hydrogen Sulphide H2S	< 0,05	OK
Oxygen O2	< 0,1 0,1 ÷ 2	OK*
Ammonium NH4 +	<2 2 ÷ 20	OK
Phosphate PO4 3-	< 2	OK
Iron and Manganese Fe3+ /Mn++	< 0,5	OK
Depositable (organic) substances	0 (Value)	**
Hardness	4 ÷ 8.5dH	OK

Table 3.6

- This data does not consider the effects of any bio-pollution present in the water
- Nominal performance data is usually declared with a fouling factor of $0.0 m^2 °C/kW$
- * Corrosion problems could arise, especially when several factors are evaluated together

3.7 Water volume and set-point temperature precision

Required restarting time, water volume, minimum load and regulation capability must be considered when the hydraulic circuit is designed.
In particular, the variation on the set-point depends on the water volume and on the regulation capability of the unit according to the relation below:

$$\Delta T = \frac{\tau \times Q}{n \times \rho \times C_p \times V} \quad (3.5)$$

- τ: Min ON Time [s]
- Q: Cooling capacity of the unit [kW]
- n: Number of compressors / steps
- ρ: Water density (1 Kg/l)
- Cp: Specific water heat (4,2 kJ/Kg°C)
- V: Installation volume [l]

3.8 Sizing the expansion vessel

If the units are not fitted with an onboard water tank and/or main pumps, it is necessary to provide an expansion vessel on site. Below is a short guide for sizing the expansion vessel of the plant.

The project elements to consider when selecting the expansion vessel dimensions for a system are the following:
- C: The quantity of water in the system, in liters
- E: The expansion coefficient of the water, calculated as the maximum temperature difference between when the system is off and when the system is running (the values are given in the table below)
- Pi: The absolute initial pressure, equivalent to the pre-charge pressure of the expansion vessel (normally 2.5 bar, i.e. 1.5 bar-r)
- Pf: The absolute tolerated pressure must be less than the pressure at which the safety valve is set, taking into account any difference in height between the valve and the expansion vessel

The total capacity of the expansion vessel is expressed as

$$Vt = \frac{c \times e}{1 - \frac{Pi}{Pf}} \quad (3.6)$$

using the expansion coefficient values in the following table.

Water Expansion Coefficient

Water Temperature [°C]	Density [kg/m³]	e (at 10°C)
10	999.6	-
20	997.9	0.0017
30	995.6	0.0040
40	992.2	0.0075
50	988.1	0.0116
60	983.2	0.0167
70	977.8	0.0223
80	971.8	0.0286
90	965.3	0.0355
100	958.4	0.0430

Table 3.7

It is also possible to calculate the average value of ‘e’ between the initial water temperature (generally assumed to be 10°C) and the operating temperature, using the following formula (where the temperature is in °C):

$$e = 7{,}5 \cdot 10^{-6} \cdot (T - 4)^2 \qquad (3.7)$$

3.9 Glycol system main recommendations

When chillers are selected to operate in zones where the outdoor temperatures are very low, it is necessary to evaluate the use of antifreeze mixtures. The use of these mixtures influences the unit performance according to Table 3.8. It is therefore necessary to consider this topic during the design phase.

Minimum Fluid Temperature with Unit Operating		5,0 °C	3,0 °C	-5,0 °C	-10,0 °C	-18,0 °C	-28,0°C
Freezing temperature		0 °C	-4,4 °C	-9,6 °C	-16,1 °C	-24,5 °C	-35,5 °C
Percentage of ethylene glycol by weight	%	0%	10%	20%	30%	40%*	50%*
Correction factors	%	0%	10%	20%	30%	40%	50%
Cooling capacity	R0	1	0,985	0,98	0,97	0,96	0,95
Compressor power consumption	P0	1	0,995	0,99	0,98	0,98	0,97
Volumetric flow rate	L0	1	1,02	1,05	1,08	1,10	1,14
Evaporator pressure drop	C0	1	1,10	1,25	1,40	1,60	1,7
Correction factors	%	0%	10%	20%	30%	40%	50%

Adjusted cooling capacity = Nominal cooling capacity × R0
Adjusted compressor power consumption = Nominal absorbed power × P0
Adjusted volumetric flow rate = Nominal volumetric flow rate × L0
Adjusted evaporator pressure drop, water side = Evaporator pressure drop × C0
* Glycol mixtures with concentrations higher than 30% must be managed on request
Note: Adjustments are measured with the same evaporator inlet and outlet temperatures 12/7ºC.

Table 3.8

3.10 Fouling factor

Usual operating conditions are based on a fouling factor of 0.043m^2/KW and therefore datasheets must be based on these values since usual calculated and declared performance are based on clean conditions of tubes (fouling factor of 0.0m2/KW), according to all relevant standards.
Data for correction multiplication factors are produced in relation to Table 3.8

Fouling factor		m^2/kW	0	0.018	0.043	0.088	0.132	0.172
Cooling capacity		C0	1	0.990	0.986	0.956	0.940	0.922

Adjusted cooling capacity = Nominal cooling capacity × C0

Table 3.9

4 Noise impact

Once the unit is installed, several factors must be evaluated to ensure a value for the noise level that is within the specific limit of the site.
If the equipment must be located in close proximity to a building, it could be placed next to an unoccupied space such as a storage room, mechanical room, etc. It is not recommended to locate the equipment near occupied, sound sensitive areas of the building or near windows. Locating the equipment away from structures will also prevent sound reflection, which can increase levels at property lines, or other sensitive points.
When physically isolating the unit from structures, it is a good idea to not use rigid supports, and to eliminate any metal-to-metal or hard material contact, when possible. This includes replacing spring or metal weave isolation with elastomeric isolators.

4.1 Preliminary consideration

The field of frequency that is audible by the human ear ranges from approximately 20 Hz to 20 KHz. This means that we can perceive vibrations within this field which, by compressing and decompressing the layers of adjacent air, produce variations in pressure that are perceived by the human ear then transformed into sound.
The simplest, most intuitive way of imagining a sound source and the vibrations it produces is to think of a stone being thrown into a pond.
As its intensity depends on the size of the disturbance applied, the surface disturbance produced is shown in a series of concentric circles (waves) which gradually move outwards. The larger the stone thrown, the greater the energy transferred to the liquid mass and propagated in the medium (water) with the movement of the waves.

Decibels

"Sound sensations" are variations of sound pressure. Human perception of sound pressure variations varies in a logarithmic perspective, i.e. considerable increases in sound pressure are necessary in order to produce significant variations in the auditory sensation. It was therefore decided to use a suitable unit of measurement that is able to relate the cause-effect relationship adequately. This made it possible to report the wide range of variations in pressure perceptible by the human ear on a limited scale. The lower limit is 0 (minimum threshold) and upper limit 120 (pain threshold).
The unit of measurement in question is the "decibel", that is ten times the logarithm (base ten) of the relationship between two uniform amounts, i.e. the one under examination and the reference.

Sound power

Sound power is the amount of sound energy emitted by a source during a given unit of time. As is the case for pressure, the sound power can register a wide range of values. Therefore, it is best to use the decibel as the unit of measurement. This introduces the concept of sound power levels calculated using the relation:

$$L_{wi} = 10 \times log\left(\frac{W_i}{W_0}\right) \ [dB(A)] \quad (4.1)$$

where:

- Wo = the reference power assumed equal to 10-12 [W]
- Wi = the power being examined [W]

Analysis of (4.2) shows that doubling the sound power leads to a 3 dB increase in the level of sound power

$$W_2 = 2 \times W_1 \rightarrow \Delta L_w = 10 \times log(2) = 3dB \quad (4.1bis)$$

Note Sound sensations depend both on pressure values and frequency. Considerable sound pressure is required at low frequencies in order to produce the same auditory sensation registered when frequencies are high and pressure levels are lower.

Sound pressure

Sound pressure is the "perceived" noise level and it is calculated using the relation:

$$L_{pi} = 10 \times log\left(\frac{P_i}{P_0}\right)^2 = 20 \times \log(10) \times log\left(\frac{P_i}{P_0}\right) \quad [dB(A)] \quad (4.2)$$

where:

- Po is the lowest pressure perceptible by the human ear (equal to 20 * 10^{-6} Pa, and a million times lower than the maximum perceptible value)
- Pi is the pressure being examined

The value calculated using (1) shows how much greater the pressure under examination is when compared to the reference pressure.
Note: In order to calculate the pressure level resulting from a source that is emitting sound energy, it is fundamental to know the distance from this source and the direction of the noise propagation.

Octave band

The sound perceived by the human ear consists of components with different frequencies. In the field of available frequencies one normally refers to those towards which the human ear is most sensitive, i.e.:

Octave band								
Hz	63	125	250	500	1000	2000	4000	8000

Table 4.1

Corrections in the octave band

Moreover, our ears are particularly sensitive to sounds between 1000 and 4000 Hz. At the same sound pressure, they consider the level of those noises that are not included in this range of frequencies to be lower.
It is therefore necessary to refer to a weighted scale in order to calculate an indicative number of the auditory perception and sensations of the ear.
The corrections that must be made to the values in the range of frequencies are shown below

Corrections in the octave band								
Hz	63	125	250	500	1000	2000	4000	8000
Corrective factor	-26	-16	-9	-3	0	+1	+1	-1

Table 4.2

The result of the corrections made is the weighted level of sound power or pressure "A" expressed in dB(A).
Sound pressure tests are carried out with a phonometer using this weighted scale. This instrument is able to measure sound in terms of the only parameter that can be detected, that is, pressure. In order to provide similar answers to those of the ear, the phonometer filters the values in the octave band.

4.2 Preliminary considerations regarding noise propagation

When selecting or comparing different chillers, it is common practice to pay attention to the values of the noise pressure levels reported in dB(A). Often, however, one neglects the fact that this value is strongly influenced by external factors:

- Distance from the source
- Operating environment
- Level of background noise

On the basis of the above, it is clear that when a manufacturer supplies the noise data for its machines in terms of noise pressure, it must specify exactly what test conditions these values refer to, especially the following:

- The distance from the subject source
- The operating environment (represented by Direction factor Q)

It is, however, still necessary to observe some basic principles regarding the applicable conditions of noise propagation laws:

- Point source
- No obstacles between the source and the receiver
- Tests carried out from the noise centre of the subject source.

Noise propagation in free or open fields

When discussing noise propagation, especially at a certain distance, we must consider that the reflections of the surrounding surfaces add considerably to the noise of the single source.
Surface materials can be more or less noise absorbent and cause a different noise response.
As a result, we usually resort to the abstraction of the **free field**, where there is no reverberation, or the **open field**, where there are no reflective vertical walls near the source and/or the point in which the noise is being assessed.

Now consider a shiny point source in a free field that has a certain noise power. Assume that the field is isotropic, i.e. the energy is irradiated in the surrounding space evenly in all directions and with the same intensity.

In this symmetrical condition, we can assume noise propagation in spherical waves.
The relation expressing the link between the noise pressure level LP in the area surrounding the source and the level of noise power of the LW source is:

$$L_P = L_w + 10 \times Log\left(\frac{1}{4 \times \pi \times r^2}\right) = L_W - 20 \times Log(r) - 11 \quad [dB] \qquad (4.3)$$

where r [m] is the distance of the point of observation from the centre of the source.

4.3 Type of noise field

In the presence of a non-isotropic source or limitations of the free field towards which the noise power is irradiated, a direction factor Q is applied. Calculated in relation (4.3), it allows the variations in the values of noise pressure levels ensuing from the different ways an isotropic source positioned near a surface irradiates power to be considered.

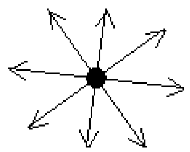
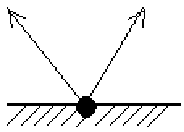
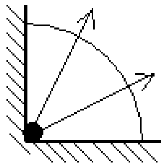
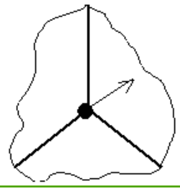
Noise field				
Source position				
Direction factor	Q=1	Q=2	Q=4	Q=8

Table 4.3

Considering the source direction factor, the relation (4.3) changes as follows:

$$L_P = L_w + 10 \times Log(Q) - 20 \times Log(r) - 11 \quad [dB] \qquad (4.4)$$

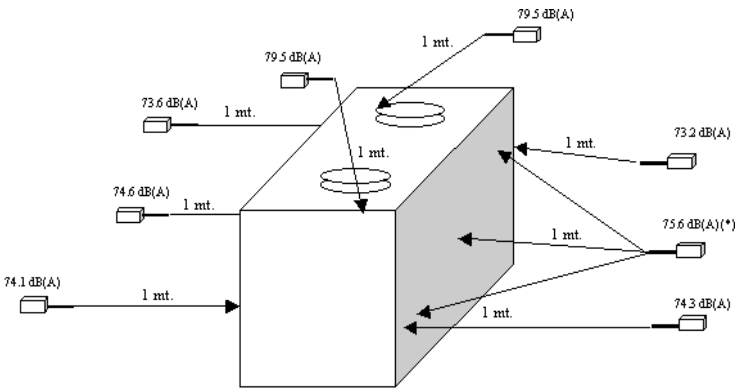
Therefore, the noise pressure level increases the log (Q) tenfold:

- Q = 1 -> + 10 * 0 = 0
- Q = 2 -> + 10 * 0.3 = 3
- Q = 4 -> + 10 * 0.6 = 6
- Q = 8 -> + 10 * 0.9 = 9

Given the overall or partial noise power value with reference to the band of octaves, taking a value for ‘r’ (usually for outdoor installations manufacturers refer the data to r = 10 m) and considering a value for ‘Q’ (usually Q = 2, source on a flat level), we can calculate the total or partial noise pressure levels in the octave band.

4.4 Distance from the source

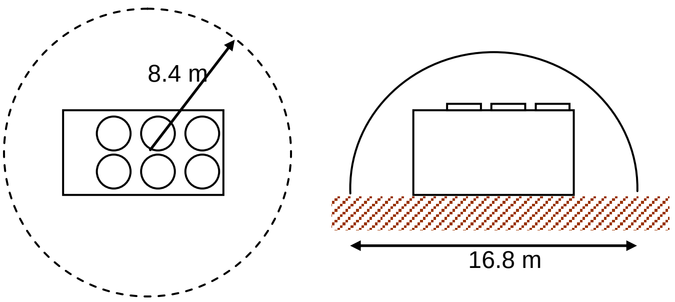
Careful assessment of these formulae allows us to state that the level of noise pressure, resulting from a given source, decreases when there is an increase in the distance from the source itself. In particular, each time the distance from the center of the source doubles, the level of noise pressure decreases by 6 dB. In the same way, each time the distance is halved, the starting level increases by 6 dB.
The above is certainly valid in those cases where the source in question is a point source or the data refers to sufficiently adequate distances compared with the machine proportions, permitting a measurement that is only minimally affected by errors. In fact, if the assessment is made at a short distance from the machine, the point source hypothesis fails, and consequently so does the validity of the above-mentioned relations. Certainly, the value calculated using known relations will not agree with the noise pressure values detected by positioning a phonometer around the different sides of the machine (compressor, coil, fan side etc.). Moreover, if the phonometer is set at a meter from the coil, it will see much of this from farther away than a meter.



Pic. 4.1

Pic. 4.1 provides an example of how, by taking different measurements in various directions at a meter from the external surface, the values registered are clearly different one from another. This makes it impossible to provide a single value at 1 meter that completely characterizes the noise source.

Experience has taught us that, in order to be significant, the measurement should be made at least one and a half times the largest diagonal of the machine. This means that in an average-sized, 5 x 2.5 m, cutting machine tests must be carried out at a distance of at least 8.40 m from the noise centers (Pic. 4.2).



Pic. 4.2

Many manufacturers, however, still play on the distance from the machine and/or direction factor, in order to register increasingly smaller noise pressure values.

In particular, some manufacturers provide a noise pressure datum taken at a distance of 1 meter from the machine. However, considering that has been previously discussed, which direction does this value refer to?

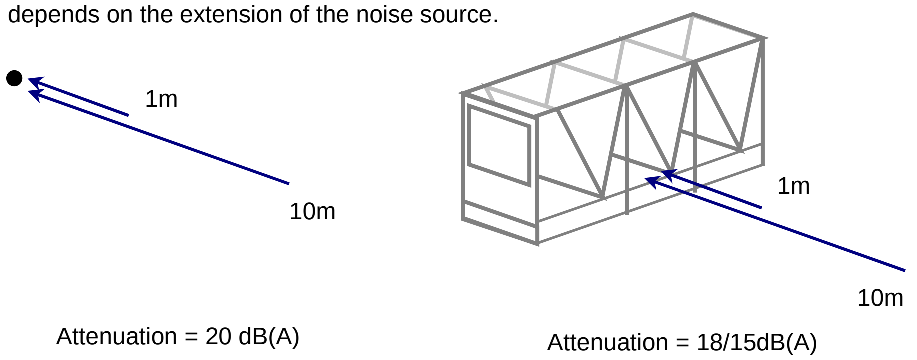
To summarize: In order to make a correct comparison between different noise pressure measurements, it is necessary to:

- consider the same distance from the source
- consider the same kind of noise field
- consider the same side of the machine

4.5 Correct evaluation at different noise pressure positions

Distance from the source

Attenuation depends on the extension of the noise source.



Pic. 4.3

Considering a point source, the attenuation observed on the noise pressure level value moving from distance Drif to distance D was given by:

$$A = 10 \times log\left(\frac{D^2}{D^2{}_{rif}}\right) \quad (4.5)$$

If, however, we examine the attenuation of the noise pressure level of a non-point source at different distances, we must consider the size of the emitting surface.
Taking into consideration an emitting surface of dimensions L and H, (5) must be modified as follows:

$$A = 10 \times log\left(L^{\frac{(3\times L+1)}{D}} + H^{\frac{(3\times H+1)}{D}} + D\right) - 10 \times log\left[\left(\frac{D^2}{D^2{}_{rif}}\right) \times \left(L^{\frac{(3\times L+1)}{D}} + H^{\frac{(3\times H+1)}{D}} + D_{rif}\right)\right] \quad (4.6)$$

$$A = 10 \times log\left(\frac{\left(L^{\frac{(3\times L+1)}{D}} + H^{\frac{(3\times H+1)}{D}} + D\right)}{\left(\frac{D^2}{D^2{}_{rif}}\right) \times \left(L^{\frac{(3\times L+1)}{D}} + H^{\frac{(3\times H+1)}{D}} + D_{rif}\right)}\right) \quad (4.7)$$

Noise field type

Another factor that must be considered is the Direction Q, with the relation:

$$L_P = L_w + 10 \times Log(Q) - 20 \times log(r) - 11 \quad [dB] \quad (4.4)$$

Unit Installation		
Position	**Direction Factor**	**Impact on Final Noise Value (Compared to Nominal Conditions, i.e. Q=2)**
Without any barriers (ideal, not feasible)	Q=1	-3 dB(A)
On the floor	Q=2	0 dB(A)
On the foor, near to a wall	Q=4	+3 dB(A)
On the floor, in an angle	Q=8	+6 dB(A)

Table 4.5

Unit side

Experimentally, we can verify that considerable variations are registered if measurements are made at different positions around the unit:

- if the measurement is taken from the front of the control panel there is a 3dB(A) attenuation;
- if the measurement is taken from the rear of the unit there is a 4dB(A) attenuation

5 Electrical Circuit

5.1 Redundancy options (single, redundant, separate)

When designing systems for which an uninterrupted service must be ensured, reliability is fundamental.
Technological environments, i.e. rooms which contain technological equipment and/or particular processes that require uninterrupted, optimum operating conditions, as well as many industrial processes, very often have breakdown costs higher than the cost of the equipment itself.
Creating a reliable system means choosing both a unit that is intrinsically reliable, and therefore designed and built in such way as to ensure an extremely low breakdown and inefficiency percentage, as well as creating suitable reserves: the system is equipped with one or more additional units, and for this reason the Uptime Institute introduced the Tier Classification based on “N+1” or “N+N” redundancy.
In the 1960s, the Uptime Institute introduced the Tier Classifications, where each Tier level provides an availability value for the datacenter. For example, Tier IV requires 2N redundancy for the connection for all the units to a BMS and the installation of an uninterrupted power supply system.

TIER Levels				
	TIER I	**TIER II**	**TIER III**	**TIER IV**
Number of delivery paths	1	1	1 active 1 passive	2 active
Redundancy	N	N+1	N+1	2 (N+1)
Compartmentalization	No	No	No	Yes
Currently maintainable	No	No	Yes	Yes
Fault tolerance to worst event	None	None	None	Yes

Table 5.1

Last generation data centers are designed with a Tier III or IV level, both of these solutions require/suggest a secondary power supply line (in particular TIER IV).
The possibility to connect the unit to a secondary power supply introduces some important benefits for the reliability of the entire system, ensuring advantages on controls, on restarting procedures and on the operational reliability of the units.
For example, in case of power failure the restart time should consider also the reboot of the microprocessor and the compressor main board. It is possible to reduce the restarting time by means of a separate power supply for the microprocessor controls.
When an external UPS is installed and connected to the chiller, if the power supply is restored after a failure, the control main board will restart the unit immediately without any delay related to hardware or software rebooting.
Another point is that the electrical heaters, which are installed on a chiller, are a fundamental detail for the continuous operation:

- If the anti-condensation heater in the electrical board is not energized, the electrical components are not maintained within their operation limits.
- If the antifreeze heaters are not energized and the chiller does not have the correct antifreeze mixture, the water circuit could be damaged.

In the following tables the different solutions for power supply redundancy are explained.

Power supply options						
Solution	**Description**	**Power Connections**	**Changeover**	**Advantages / Disadvantages**	**Restarting Procedure**	**BMS Connection**
Standard power arrangement	Single power supply for the full unit (compressors, fans, pumps, heaters and control boards)	1 x 400V	Not available	In the event of a power supply failure the unit is switched-off. Heaters are not energized.	Once the power supply is restored the unit restarts automatically	During power loss the BMS does not receive any information from the unit
Separate power supply for control boards and auxiliaries[2]	Single power supply for compressors, fans and pumps and separate power supply for control boards (unit & compressors) and auxiliaries	1 x 400V 1 x 230V	Not available	In the event of power supply failure the unit is switched-off. Heaters are energized and protect the unit. Main board remains continuously active.	Once the power supply is restored the unit restart automatically. Full load in 2 minutes[1].	During the power loss the unit communicates the status and the circuit parameters to the BMS
Separate power supply for pump/s, control boards and auxiliaries[2]	Single power supply for compressors and fans and separate power supply for control boards (unit & compressors), pump/s and auxiliaries	1 x 400V 1 x 400V	Not available	In the event of power supply failure the unit is switched-off. Heaters are energized and protect the unit. Main board and pump/s remain continuously	Once the power supply is restored the unit restart automatically. Full load in 2 minutes[1].	During the power loss the unit communicates the status and the circuit parameters to the BMS

				active.		
Automatic[3] double power supply with ultracapacitor	Double power supply for the entire unit (compressors, fans, pumps, heaters and control boards) with automatic changeover	2 x 400V	Automatic[3]	In the event of power supply failure, the unit is switched-off and it commutates to the backup line in 10 seconds. Heaters are not energized for 10 seconds Mainboard remains active during the commutation for 2 minutes[4]	Once the power supply is restored the unit restart automatically. Full load in 2/3 minutes[1] for power failures shorter than 2 minutes[4]	During power loss, the unit communicates the status and the circuit parameters to the BMS for 2 minutes[4]
Automatic[3] double power supply & separate power supply for control boards and auxiliaries[2]	double power supply for compressors, fans and pumps with auto-changeover and separate power supply for control boards and auxiliaries	2 x 400V 1 x 230V	Automatic[3]	In the event of power supply failure, the unit is switched-off and it commutates to the backup line in 10 seconds. Heaters are energized and protect the unit. Mainboard remains continuously active.	Once the commutation procedure is completed the unit restarts automatically. Full load in 2/3 minutes[1] from the procedure conclusion	During power loss the unit communicates the status and the circuit parameters to the BMS

See tables on dedicated Technical Specification documents for each range values.

1. The terms auxiliaries are: crankcase, water, and electrical board heaters
2. The ATS is included in the unit. Once the main line is restored the unit commutates automatically to that line (settable).
3. This is valid if the power supply has been active for more than 5 minutes before power failure. A shorter time reduces the microprocessor time ON. For units equipped with power phase capacitors, these devices do not work for 5 minutes after each commutation in order to allow complete energy dissipation (according to the EN 60831).

Table 5.2

Summary

The correct configuration really depends on the expectations for the project, i.e.

- Is a 230V UPS available? If so, the best solution is to have a separate power supply for the controller and heaters, i.e. 400 V + continuous 230 V separate power supply form UPS.
- Is a 400 V UPS available? If so, the best solution is to have a separate power supply for the controller, heaters and main pumps, i.e 400 V + continuous 400 V separate power supply from UPS.
- Is a large 400 V UPS available? If so, the best solution is to have a separate power supply for the controller, heaters, main pumps, free-cooling pump and fans, i.e. 400 V + continuous 400 V separate power supply from large UPS.
- Is an external UPS (or genset, or power line) available? If so, the best solution is double power supply (ATS) integrated into the unit. With this solution the unit is fitted with an onboard capacitor that maintains active the control board during the commutation between line A to B, i.e. 400 V & 400 V separate power supply.

5.2 Electrical data

Good practices and recommendation for electrical systems

The correct design for the electrical section depends on many factors, partially covered by the unit data, that must be considered and matched.
In particular, protection sizing depends on cable size and lengths, as well as local standards.
Main electrical data provided for the units are Full Load Amperage (FLA), Full Load Input (FLI) power and Locked Rotor Amperage (LRA). Those values are necessary for designing the site electrical circuits as per the explanation below, while operative values for current and power are not to be used for sizing cabling, safety devices and other devices since different values may happen according to the different operating conditions.

Electrical data for components

- ST: It is the starting mode for compressors. It can be Part-Winding (PW) or Star/Delta (Y/D) according to the model (see below the specific note)
- FLA: Full Load Amperage. These are the absorbed current values of components [A] at max operating parameters over an extended period of time.
- FLI: Full Load Input Power. These are the absorbed power values of components [kW] at max operating parameters over an extended period of time.
- LRA: Locked Rotor Amperage. This is the max current peak of components [A]. Regarding the LRA for compressors refer to the note below.

Electrical data for the unit

- Voltage: The typical power supply for mid-large chillers in 50Hz countries is 400V / 3ph / 50Hz or 400V / 3ph +N / 50Hz, with a tolerance in voltage of 380 V-5% and 420+5%. Therefore, the minimum voltage is 360 V while the maximim is 440V. The unit is protected from voltage conditions that are outside of these limits and it is automatically switched off by means of the min/max voltage relay. This means that units monitor:
  - Minimum and Maximum voltage, considering the note below
  - Asymmetry
  - Missing phase
  - Sequence phase

  NOTE: On board voltage relays feature 1 second sample time. Therefore, they do not protect the unit in the event of extremely quick spikes. If the power grid can be affected by such events, it is suggested to install a proper device.
  Versions with different power supplies (voltage and/or frequencies) can be provided on request, with the same limitations as usual power supply.
- Frequency: Cooling units are usually designed according to the EN60204 (electrical circuit design) and EN50160 (voltage quality) standards.
  In particular, according to the EN50160 standard, the average frequency values provided by the power grid, referred to a 10 s timeframe, must be
  - 50Hz +/- 1%, i.e. 49,5 - 50,5Hz on 99,5% of the year (8716 hours)
  - 50Hz +4%, - 6%, i.e. 47 - 52 Hz) on 100% of the year
- Harmonics distortions: Chillers are designed to operate correctly within certain limits of THD values. Best practices indicate 5% of the pick as an admitted value for THDu.
  THDu values higher than 10% generate unpredictable unit operation and failures. THDu status monitoring is usually carried-out by means of a spectrum analyzer which is not part of the chillers arrangement.
- SB: Stand-by current: this is the current absorption [A] of the auxiliary devices. When the unit is in stand-by mode it refers to current absorption without compressors, fans and pump (if fitted) operating.
- OA: Operative Amperage. This is the absorbed current calculated by simulation software at a specific operative condition over an extended period of time, i.e. compressor/s operative absorbed current + operative fans absorbed current + operative main pump absorbed current (if present, typically considered separately in the simulation software datasheets). This is the operative steady current value at specific conditions. Since, according to the different operating conditions, different current values may happen, this value is NOT to be used for sizing cabling, safety devices, etc.
- OP: Operative Power input. This is the absorbed power calculated by simulation software at a specific operative condition over an extended period of time, i.e. compressor/s operative absorbed power + operative fans absorbed power + operative main pump absorbed power (if present, typically considered separately in the simulation software datasheets). This is the operative steady power value at specific conditions. Since, according to the different operating conditions, different power values may happen, this value is NOT to be used for sizing cabling, safety devices, etc.
  Data for units fitted with power phase capacitors refer to the worst case, i.e. without power phase capacitors active.

- FLA: Full Load Amperage, the maximum absorbed current of the unit [A]. This is the absorbed current of the unit at maximum operating parameters over an extended period of time, i.e. compressor/s max absorbed current + max fans absorbed current + maximum main pump absorbed current (if present) + the auxiliary devices current (SB). This is the maximum steady current value actually necessary to size cabling, safety devices, etc.
- FLI: Full Load Input Power, the maximum absorbed power of the unit [kW]. This is the absorbed power at maximum operating parameters over an extended period of time, i.e. compressor/s maximum absorbed power + fans absorbed power + maximum main pump absorbed power (if present). This is the maximum steady power value actually necessary to size cabling, safety devices, etc. In combination with the FLA value.
- LRA: Locked Rotor Amperage, the maximum absorbed pick in current of the unit [A]. This is the max current peak of the unit, i.e. compressor nr 1 locked rotor amperage + other compressor/s max absorbed current + max fans absorbed current + max operating current for pump (if fitted) + the auxiliaries devices current (SB).
  This is necessary to define the delay in external safety devices and the genset sizing (if fitted). Data for units fitted with power phase capacitors refer typically to the worst case, i.e. without power phase capacitors active.

Note

- **Units fitted with oil-free centrifugal compressors**
  For units fitted with oil-free centrifugal compressors (generally called “Turbocor” by the main manufacturer brand), the LRA is not applicable since the compressors are based on an inverter driven motor connected to DC condensers and all the design must be based on the FLA value.
- **Units fitted with screw compressors with star/delta starting mode**
  The star/delta transition increases the absorbed current value for an instantaneous timeframe. This peak can be calculated as the following: compressor number 1 LRA (Δ) + the maximum compressor number 2 absorbed current (FLA) + the fans absorbed current (and pump if fitted). This transition is usually shorter than the minimum intervention time for protection tripping and, therefore, this value is usually not considered when protection devices are selected (under designer’s responsibility).
- **COSφ**: It is the cosine of the φ angle of displacement between the current and the voltage in an electrical system with alternate current.
  Values in the table below are provided at nominal conditions, i.e. Inlet/Outlet water temperature: 12/7°C,
  Outdoor temperature: 35°C, glycol: 0%, fouling factor: 0 m^2°C/kW and full load conditions.
- **COSφ at different load conditions**
  Standard power phase capacitors (fixed) cannot maintain a value in every condition. As the capacity for standard power phase capacitors is fixed, they cannot adapt to the load and the cosphi cannot be the same in all conditions.
- **Power phase capacitors on chillers with screw compressors**
  Regarding power phase capacitors on chillers with screw compressors it is very important to underline the following points. It is not possible to use power phase capacitors for the fans as they are connected to a phase cutting regulator; consequently, the only way to achieve a COSφ target value for the entire unit is to apply a higher value to the compressors (for instance to achieve 0.90, it is necessary to use 0.92 on the compressors).
  Regarding 0.95, this is the maximum acceptable COSφ value for screw compressors. It is absolutely not permitted to have a value higher than 0.95. This means that it is not possible to grant 0.95 for the entire unit, but only a value close to and below 0.95. The gap depends on the size of the unit which can fall within the measurement tolerances.
- **COSφ on units equipped with fans with EC motors**
  Electronically commuted (EC) motors, which are applied on EC fans, do not have the same effect as asynchronous motors with relation to the phase displacement between current and voltage.
  These types of motors do not introduce a phase displacement, but modify the shape of the wave as a phase displacement. However, this effect is different and it cannot be corrected with the traditional power phase capacitors
- **COSφ on unit equipped with pumps**
  The value for the COSφ on units equipped with onboard pumps is typically reduced by the effect of the pump and it is necessary to check the final impact on the amperage.

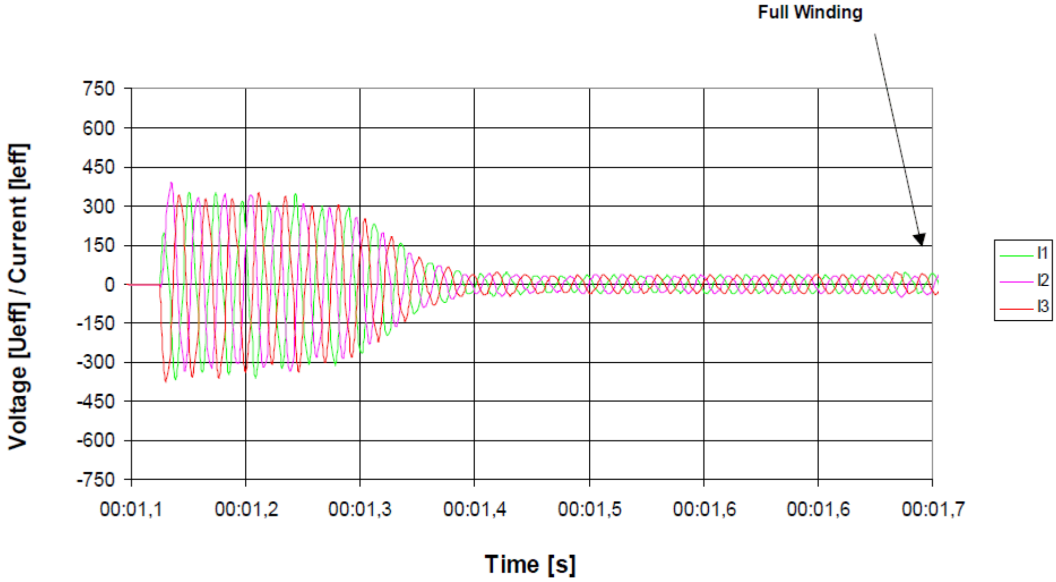
5.3 Compressor starting procedures

The starting mode changes based on the compressor model/type. Starting procedures for an electrical motor are mainly the following:

- Part-winding, as screw compressors
- Star delta, as screw compressors
- Direct-on line, as Scroll compressors
- Direct-on line with softstarters
- Inverter driven, as Variable Speed Drive scroll compressors or Oil-free centrifugal compressors

Part-winding

Part-winding: With this system, the windings of the motor are divided in two sections and are powered in two steps - 60% of the windings first, then 100%. A typical amperage profile for this configuration is shown in Pic. 5.1.
Please note that the intent of the picture is descriptive only; values for amperage and timing may change significantly according to the compressor size, model or manufacturer.

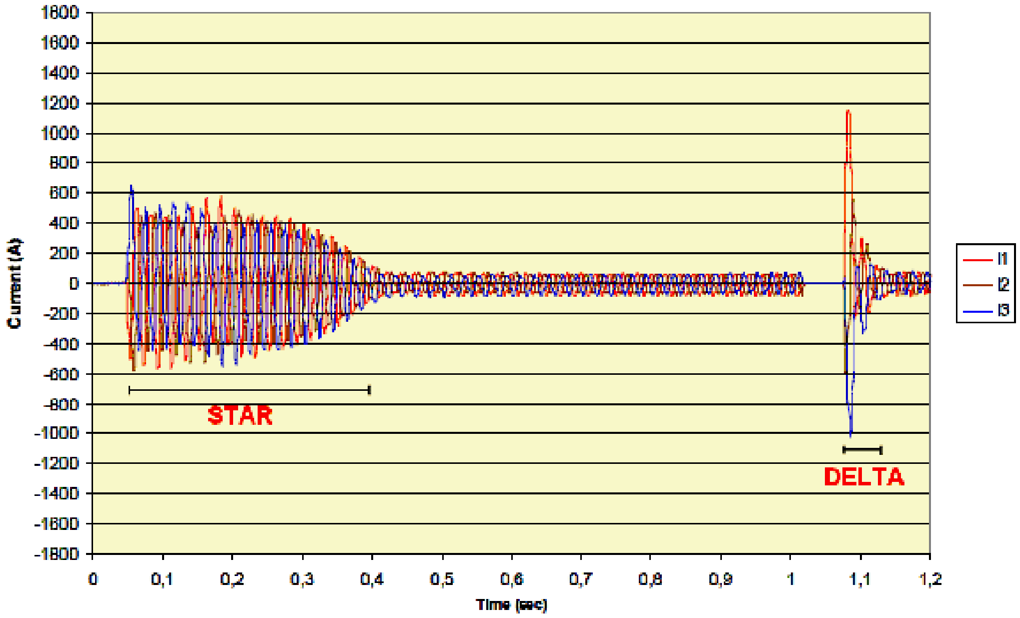


Pic. 5.1

When compressors are fitted with part-winding, the starting current value is slightly higher than LRA.
Please consider that LRA is measured according to ASERCOM standards, i.e. in specific conditions (measured at 32°C, with rotor blocked, and after 4 seconds the compressor has been powered). Therefore, these values could be slightly different in different conditions.
Note: All the values in the datasheets refer to RMS (Root Mean Square) value.
In the electrical tables, this value is identified with the “D”, while with “DD” usually identifies the Direct On Line starting method, (DOL), which is usually not applied on screw compressors.

Star-Delta

The motor is started in two configurations, Star and then Delta: the first one in a Star layout, the second one in a Delta layout. A typical amperage profile for this configuration is shown in the following picture.
Please note that the intent of the picture is descriptive only, values for amperage and timing may significantly change according to the compressor size, model or manufacturer).



Pic. 5.2

The first peak is typically lower (in current) and longer (in time) than the second one, which is higher and very short.
This is the reason why the star value is usually considered for sizing and design, while the delta value is necessary for a double check. This is why the declared data refers to "star mode".

Since it is very short, the Delta (Δ) peak is practically transparent from a current absorption prospective, but it could influence the operation of some critical devices, e.g., and it should be consequently considered in the general electrical design (under designer's responsibility).

Direct On Line (DOL start)

In Delta configuration, the whole windings are powered directly. In this way, the current profile has just one peak, featured by the width of the Delta peak and the duration of the star peak. This is the worst case in terms of current absorption and for this reason, it is not normally used for screw compressors.
This solution is usually applied with scroll compressors, which, in order to reduce the starting current, can be fitted with soft-starters.

Softstarters

Soft-starters, due to specific electronic circuits, allow a reduction in starting current for compressors fitted with DOL starting mode.
Reduction in starting current is usually 40% of the Locked Rotor Amperage. This is an average value, while the exact reduction depends on settings and operating conditions for compressors soft-starters.
The main limit to the starting current reduction is the possibility, for the soft-starter, to apply the minimum necessary torque to switch-on the motor. For this reason, the soft-starters must be applied on a DOL winding solution.
Scroll compressors are usually fitted with soft-starters since the only available winding arrangement is DOL, while screw compressors are fitted with part-winding or star-delta arrangements, which enable the starting current reduction.
A part winding mode usually shows a reduction in inrush currents of around 2.5-3 times the DOL value, while the experience of main compressor manufacturers says that soft-starters do not allow a reduction higher than 2.5 times the DOL. Therefore, the reduction given by soft-starters is roughly equivalent to the one given by the part winding.
This is related to the minimum torque which is necessary to switch-on the motor.

One of Schneider Electric vendors for screw compressor chillers has carried-out some internal tests with soft-starters and screw compressors, and they have not found any particular advantage for the reduction of the inrush current resulting from this matching.
However, in some particular conditions, the application of soft-starters allows a reduction in starting current which is higher than the values guaranteed by the part-winding mode. This is highly influenced by the size and the settings on site.

In light of these considerations, Schneider Electric does not suggest the implementation of such a solution for two main reasons. First, it is not possible to ensure a significant result in terms of inrush current reduction; second, the impact on units would be quite expensive and critical for product reliability.
While soft-starters are not suggested as a solution to reduce the impact of the starting current of large chillers, a very low starting current is ensured by oil-free centrifugal (Turbocor) chillers.
From an electrical point of view a possible solution to reduce the inrush current could be the installation of an inverter on the compressors. This would allow the start current to be between 1.3 and 1.5 times the maximum operating current.
However, this solution implies a complete review of the control and cooling circuit and has a considerable impact on the unit cost.

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