Achieving energy savings in commercial refrigeration equipment: Low pressure control

by Christophe Borlein

Executive summary

Refrigeration and air conditioning represent 15% of electrical power consumed worldwide. Although low-pressure (LP) control does not generate as significant energy savings as high-pressure (HP) control, it is nevertheless still a viable option. This paper explains how LP control generates energy savings vs. a traditional regulation and gives technical constraints to be taken into consideration.

998-2095-02-28-12AR0

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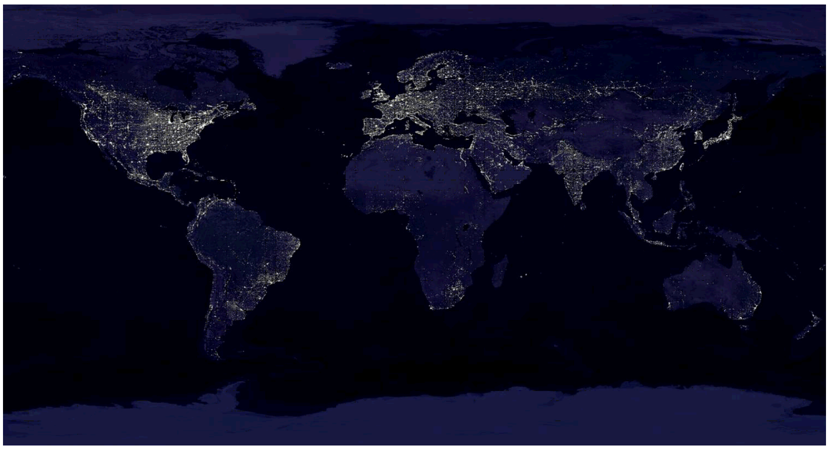
Summary

Executive summary



Electrical power consumption worldwide.

Refrigeration and air conditioning represent 15 % of electrical power consumption worldwide, that corresponds to 4,5 % of total gas emissions with greenhouse effect.

the refrigeration process use a considerable amount of energy (30 to 80%) in the food industry, storage or mid size store and hypermarkets. It is that first expenditure that users want to save money, but it is also the least known and most critical. Despite solutions that have been existing for years, the initial choice favors operation and investment rather than energy consumption.

Low pressure control (LP) is not frequently quoted when one speaks about energy savings. It is often associated with a refrigerating power reduction involving a temperature rise and said to offer little savings compared to high pressure (HP) control.

Obviously low pressure control energy savings are less important, but should not be neglected. Moreover its implementation on a new installation is technically as simple as for HP control.

LP control savings depend on the use of the installation, but more especially on the adjustments and the preliminary analysis of the installation. If not made properly, in certain cases, LP control may lead to overconsumption.

This document explains how LP control generates energy savings vs a traditional regulation and gives technical constraints to be respected.

Introduction

If compressor is the heart of an installation, Low Pressure (LP) is the artery. It is the most important pressure in terms of refrigeration. Obviously when considering the energy consumption of the compressor, it is critical to maintain the proper pressure, but there are also other considerations.

LP control is possible using electronic regulation. Although there exist many devices to fulfill this function, this solution is rarely proposed.

Low pressure control is frequently implemented in air conditioning systems, however, for mechanical systems using chilled water, it is very seldom used. This technique can be called set point modulation. Although this functionality is present, it is not very often implemented.

LP control is a viable solution and generates additional energy savings even when coupled with HP control.

Commercial refrigeration system operation

Commercial refrigerating system operation

Constitution

A refrigeration system is a thermodynamic cycle which transports heat from a cold storage, via evaporator, to the outside via condensor (Figure 1 shows a refrigeration system to locate devices).

LP, represented in blue on figure 1, is located between the expansion device and the compressor inlet (in the direction of the fluid).

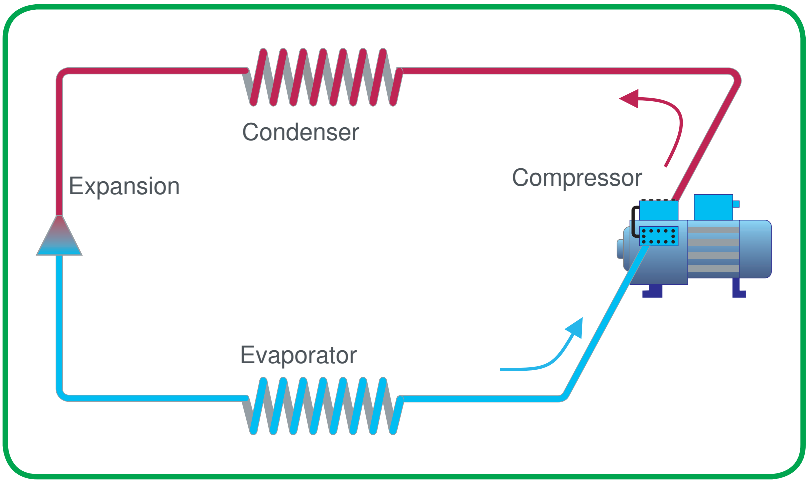


Fig.1 Representation of a refrigerating system

Compressors

Compressor is the heart of the circuit, while it compresses the gas it provides the flow necessary for the cycle. Generally speaking the compressor consumes the major portion of the energy. It's consumption is not constant and depends on several variables, most importantly are the low and high pressures. Some compressors are equipped with a mechanical device to reduce cooling capacity. The use of these partial load devices affects the compressor efficiency.

Regarding energy consumption, the most useful data is the COP (Coefficient Of Performance). The COP takes into account variation of internal compressor efficiencies and the refrigeration cycle status. It is therefore necessary to have the operating status associated with the COP to be able to make a judgment. (Example: -10 ° C / +35 ° C). COP is the ratio of the cooling capacity produced (or useful) to the consumed electrical power. The COP operates in the same direction as efficiency.

Commercial refrigeration system operation

Evaporators

In term of usage or device, evaporator is the most versatile component. An evaporator is a heat-transferring surface between the refrigerant and the fluid (or solid) to be cooled. Either the cooling element or the fluid can be moved using a fan or a pump to increase the exchange coefficient .

Evaporators manufacturers give the dissipated power according to the temperature difference between the 2 fluids.

Power dissipated with an exchanger is given by the formula [1] (to make it simpler, overheating is not taken into account). Figure 2 shows the temperature change of the fluids in the exchanger.

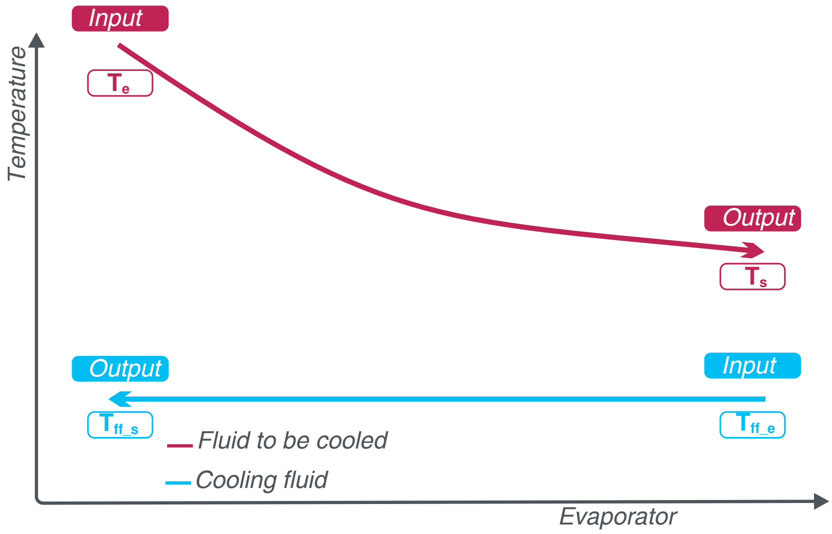


Figure 2 : Temperature variation in an evaporator

Formula [1]

$$P = K \cdot S \cdot \Delta\theta_{LM}$$

P = power dissipated [W]
K = exchange coefficient [W.m^{-2}.K^{-1}]
S = heat-transferring surface [m^2]
$\Delta\theta_{LM}$ = logarithm average temperature variation or DTLM [K] given by formula [2]

Formula [2]

$$\Delta\theta_{LM} = \frac{(T_e - T_{ff\_s}) - (T_s - T_{ff\_e})}{\ln\left(\frac{T_e - T_{ff\_s}}{T_s - T_{ff\_e}}\right)}$$

Evaporator characteristics (exchange coefficient and surface) are regarded as constants. There is thus a direct and proportional relationship between the temperature variation of the fluids and the exchanged power.

It should be noted that the coefficient of exchange can fluctuate according to several parameters

-clogging,

-ice building,

-fluid or fluid speed to be cooled,,

-overheat.

Low pressure

LP is created by the balance between the power dissipated by the evaporator, in red on figure 3, and the power generated by the compressors, in green.

When the temperature of refrigerant and the fluid are equal, there is no more exchange . Regulation of the compressors provides an opportunity to maintain this balance according to the set points.

Figure 4 shows the impact of a compressor related to the balance of LP. When the number of compressors increases, LP goes down. To meet the power demand, operation duration will change.

While the system is engaged, and the same number of compressors are in operation, the load may vary regardless of the number of evaporators. This will cause the LP to decrease as the load on the system decreases. On figure 5, operation with 2 evaporators connected to a single compressor will involve a pressure lower than with 3 evaporators. In this operation with 2 evaporators, the refrigerating power by evaporator is higher than the initial dimensioning planned for 3 evaporators, but lower than the total refrigerating power, because LP is lower.

Too low a LP increases immediatly the evaporators power (within possibility of compressors supply, when all compressors are running), LP reduction involves a reduction of the instantaneous power as shown figure 4.

Increase of instantaneous power will involve short cycles of operation at the evaporators level but also at the compressors level.

LP control consists to controll evaporation pressure to a value allowing the lowest power demand for the compressors/evaporators couple (and auxiliaries).

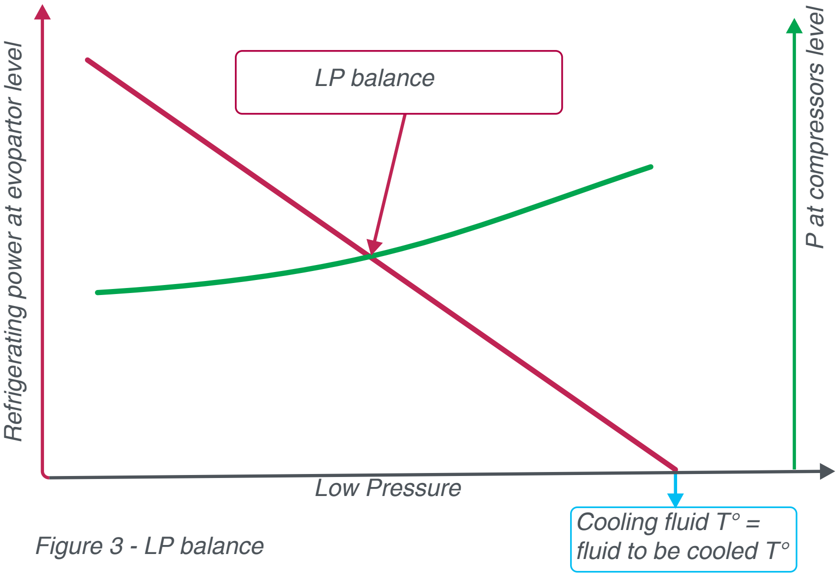


Figure 3 - LP balance

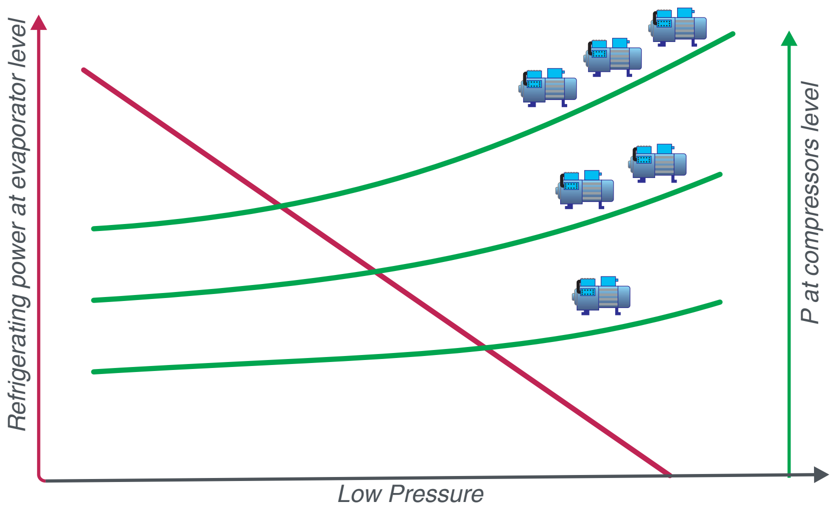


Figure 4 - Impact of the number of compressors

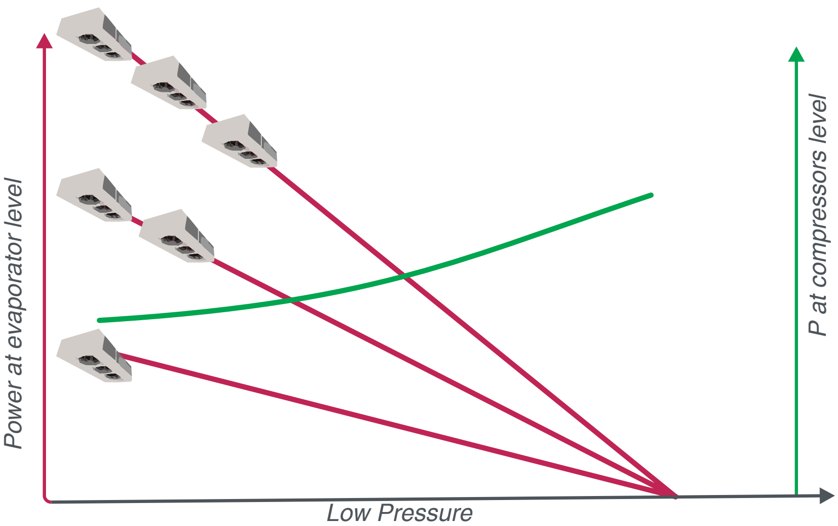


Figure 5 - Impact of the number of evaporators

LP control modes

LP regulation is done by controlling the compressors. In order to focus this white paper on LP control, means to reduce compressors power are not taken into account.

Use of variable speed drive on refrigerating machine will be the subject of a dedicated White Paper

LP regulation by hystersis

This old fashion method is still in use. It can be implemented by a pressure controller or by a regulator.

It consists of affecting pressure thresthresholds for each compressor. Figure 6 shows how stages are controlled. When the refrigerating power is the lowest, it is the same for LP .

This type of regulation is just the opposite of what is required for efficient operation, however, with typical pressure controllers you have no other choice. Figure 7 represents regulation for a system with several evaporators and compressors.

Nominal LP is reached when the load demand is at it's maximum point. At lower loads, the LP is at a lower value.

There is usually a loss of compressor performance because of this LP shift downwards.

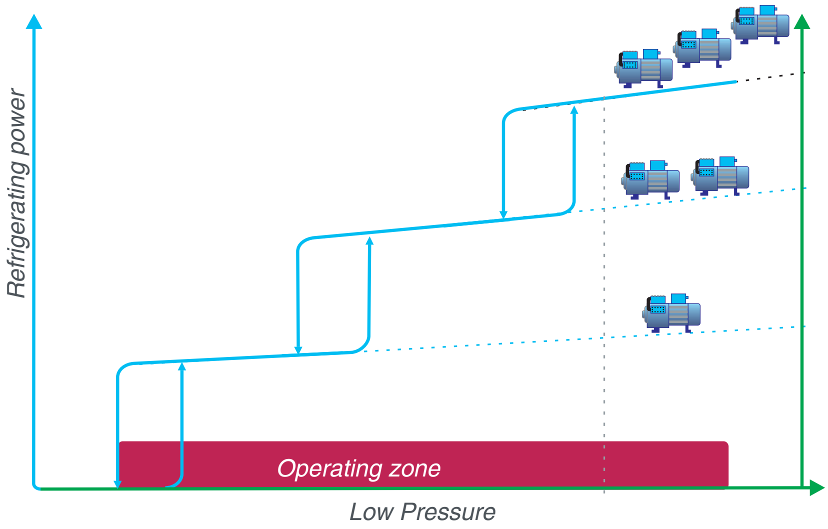


Figure 6 - Stepping regulation

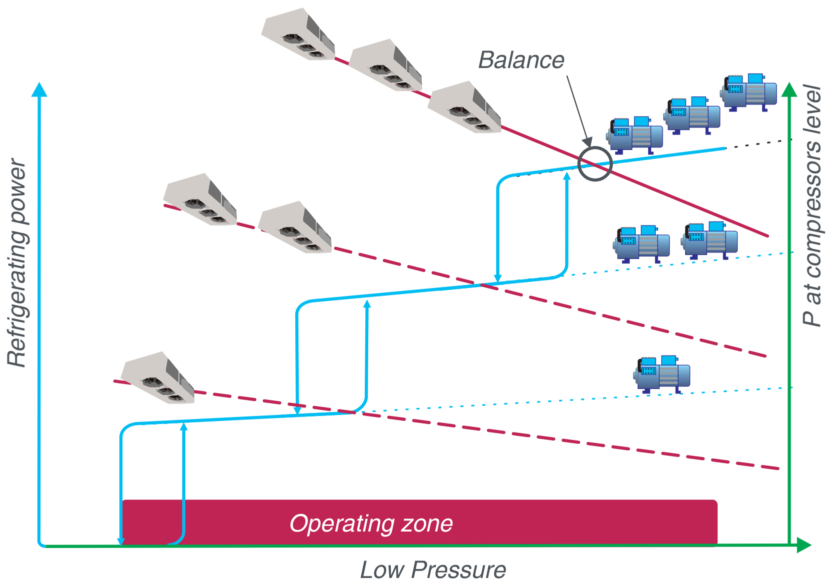


Figure 7 - Compressors regulation with mutiple evaporators

LP control modes

Constant LP

Constant LP corrects the shift problem, because pressure will be maintained more or less constant. There exist several methods of regulation, the most used are:

-Dead zone,

-PID.

Dead zone regulation (see Figure 8) consists of defining pressure limits surrounding set points in which there is no reaction of the system.

If LP exceeds the bottom or the top of these limits, a compressor is stopped or started within a time delay.

Then, if the pressure does not vary correctly, either after a time delay, or an other limit, regulation energises another compressor.

Since this regulation reacts to variations in the load, it is not possible to obtain a very stable system.

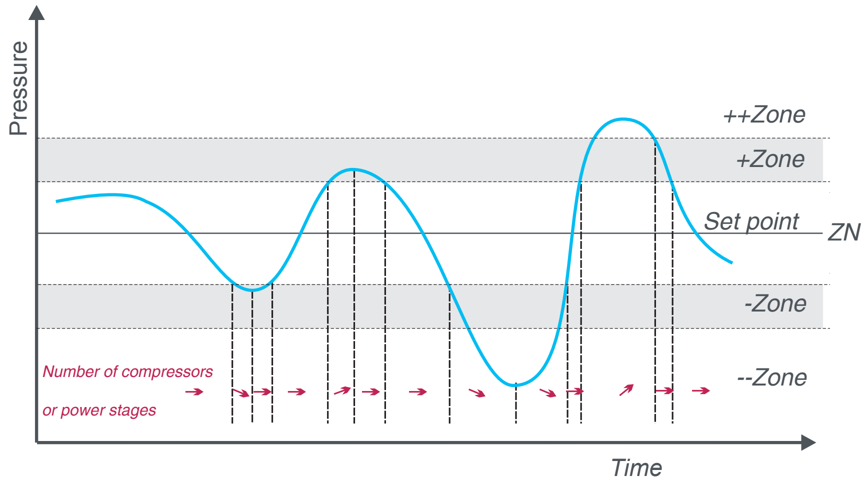


Figure 8 - Dead zone regulation

PID (Proportional Integral Derivated) regulation figure 9, is a system which makes continuous correction of the variations (proportional), stabilisation relative to the set point (Integral) and the reaction to the variations (derivative).

This method of regulation provides a system increased stability and maintains the pressure more closely to the set point. By the same token reaction of the system is faster.

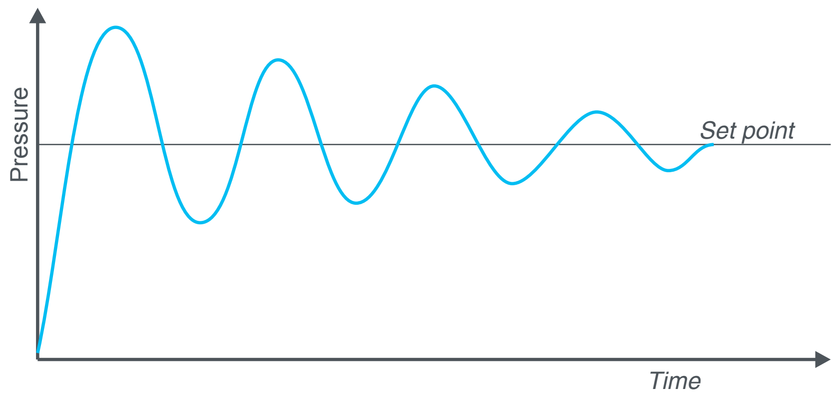


Figure 9 - PID regulation

PID regulation is perfectly suited for systems equipped with a variable speed drives.

LP control modes

Variable LP

The goal of LP control is to produce energy savings by increasing LP when possible without impacting the efficient performance of the commercial refrigeration system.

Figure 10 represents the evolution of COP according to LP for different HP. When LP increases, the COP increases. (The values being specific to the compressor, it will be necessary to make the calculation for another compressor.) The COP changes dramatically with variances in load, but with a regulation loop, such LP variations are not possible. With proper control, the variations will be only a few degrees.

Figure 11 shows for the same compressor, the percentages COP fluctuation relative to one degree of LP . Variations go from 2,6 to 3,5 %/K. Increasing LP by 2 K with the compressor used in the example, will give approximately 5,3 % to 7,1 % power saving:

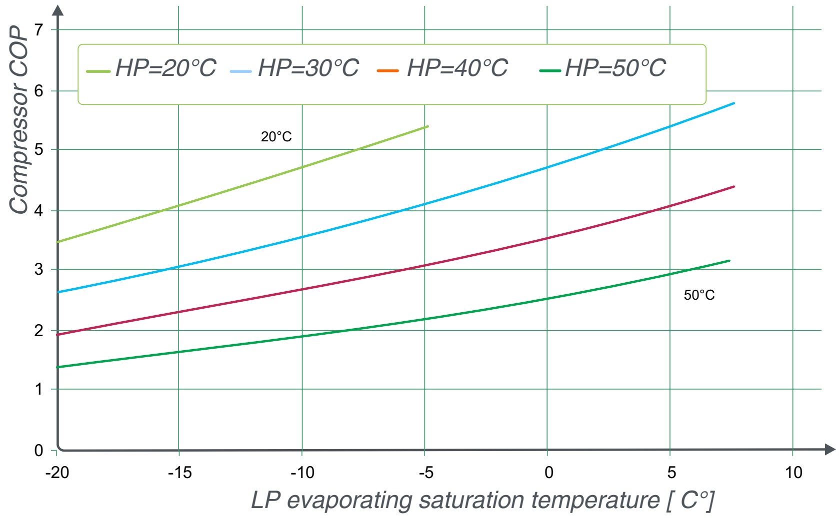


Figure 10 - COP variation of a compressor vs LP for several HP

($(1+ 0,026)^2 = 1,053$; $(1+0,035)^2 = 1,071$)

according to the mode of operation.

Increasing LP generates energy savings; however, it is difficult to find the limit that will not hurt the correct operation.

LP control use of regulation loop (dead zone or PID), the set point will change according to a parameter to be defined.

The parameters which reflect the variations of the load must be identified in order to effective adjust the LP. These parameters will also be used to define the acceptable LP variation amplitude.

These parameters must consider the load variations on the evaporator which can be caused by:

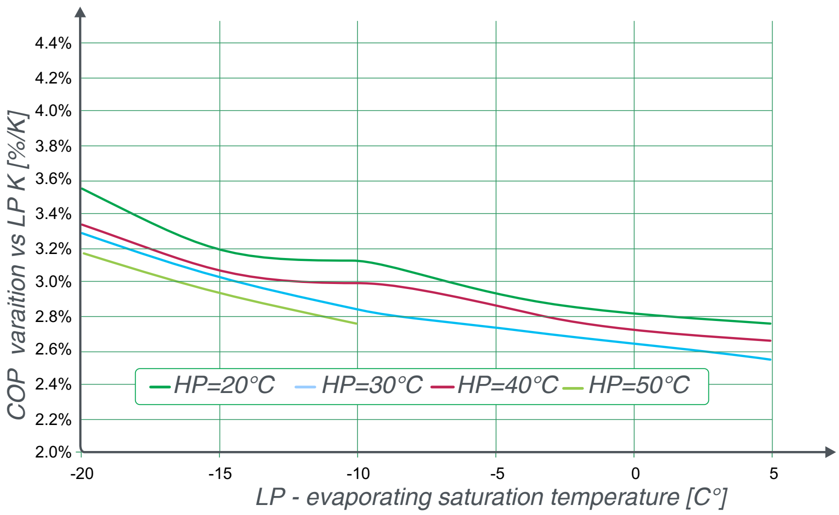


Figure 11 - COP variation vs K of LP

-inside temperature,

-outside temperature,

-product flow,

LP control modes

-humidity,

-…

For example with commercial refrigeration equipment, the needs will vary according to the outside temperature. When the outside temperature is equal to the storage temperature (for a positive storage), the needs will correspond to the internal contributions. Let us say that those correspond to 20% of the nominal power, it would be possible to assume that the variation in temperature between the set point and LP can be reduced by 80%, except that is not realistic.

A large reduction of the temperature gap will have a significant impact on the coefficient of exchange of the exchanger, which will reduce the performance and efficiency.

Moreover, the most restrictive factor will be overheating. It is not possible (without modification) to reduce the difference (between LP and the set point for counter-current circulation, between output temperature and co-current temperature) to a value lower than overheating plus 1°C. This calculation must be made on the most constraining evaporator. According to the differences between the most constraining and the others, the replacement or the modification of this one can prove to be profitable.

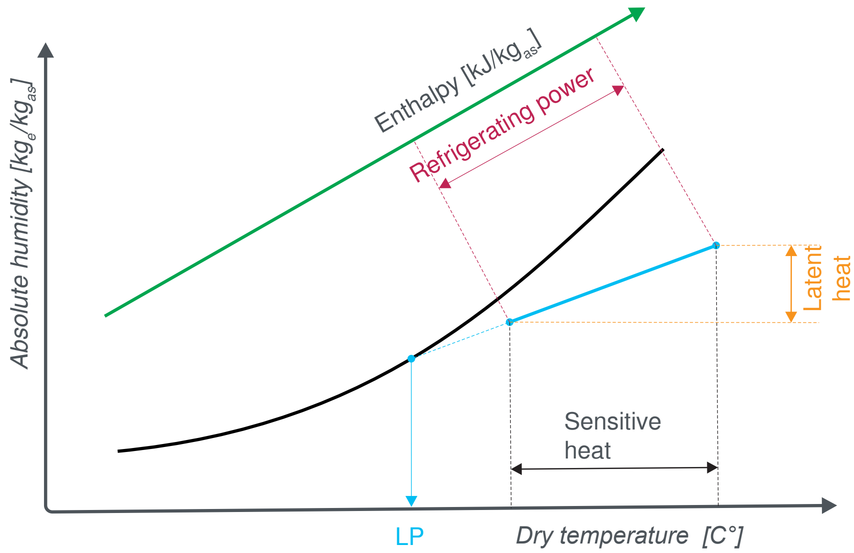


Figure 12 - Representation of the air evolution on the diagram of humid air.

Indirect benefits

In certain cases, LP variation involves indirect benefits (complementary energy savings). In an air evaporator, increasing LP will reduce the share of cooling in latent power. That is to say that the air will be less dried and that there will be less energy used for drying. Figure 12 diagram represents the evolution of air vs. humid air. If this line is steeper, the air will be more dried and the need for refrigerating power will increase, with no change to the air temperature. Variations in the LP temperature effects the degree of variation of the slope of curve. If LP is higher, the slope will be steeper. Figure 13 represents the share of the latent heat on the power of evaporator for a cold room at 2°C; 80% according to LP.

Changing from 12 K down to 8 K will involve a 10% complementary profit. This profit is to be abounded, because calculation is made with constant intern condition, whereas relative ambient moisture will increase.

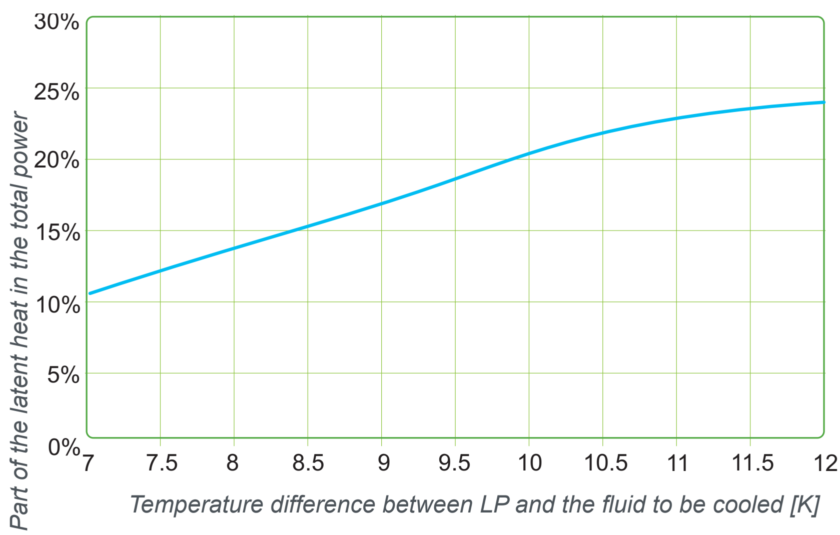


Figure 13 - Part of the latent heat in the exchanged power

LP control modes

Determination of the right LP

During calculations of LP control and energy savings, it is necessary to take into account other factors like pumping or ventilators for evaporators. When there is no regulation on these devices, increasing LP is the best solution. If there is a regulation, it is necessary to take this regulation into account in order to define LP which allows the lowest power consumption.

Varying the ventilation rate in buildings is a common practice used today in an effort to reduce energy consumption. With LP control, when LP increases the instantaneous power is reduced at the evaporator level, which requires to run the evaporator longer and thus the ventilators for the same need.

Oppositely, decreasing LP will reduce the operating time of the ventilators. Figure 14 represents the average power of the compressors and evaporators in a cooling store.

A basic LP control calculation would have given -26°C for the LP. On this example, taking into account a controlled operation of the ventilators, consumption is reduced by 7% for an 8°C outside temperature.

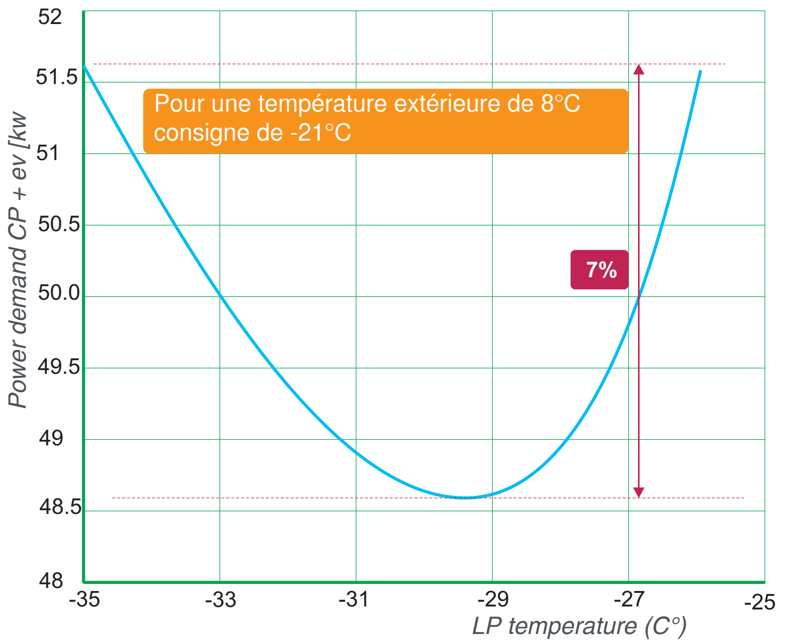


Figure 14 - Compressors and evaporators power according to LP

Concretely on the field

Compared to a traditional system using neutral zone or PID, LP control will request:

- an additional feedback (for example an external temperature sensor);

- a regulation algorithm.

For this practical implementation it is necessary to add calculation of setting points and a commissioning on the job site.

LP control needs a dedicated regulation device. This regulator will have two functions:

- define the LP setting point;

- control the actual LP.

LP regulation requires data acquisition. A pressure transmitter is thus connected to the regulator, as well as for the traditional constant LP regulators.

To determine the LP setting point, the regulator needs one or more additional data. This information characterizes the variation of the request. If it the outside temperature, a temperature transmitter must be added.

Compressors can be controlled either by traditional means (on/off, power controller, electromagnetic discharge valve etc.); however, use of a variable speed drive to control at least one compressor allows to maximize the benefits of LP control.

Implementation of LP control is, technically, fairly easy. Only one probe must be added to the regulation device which is used for constant LP.

Difficulty lies in:

- the choice of the right data for the setting point, taking into account the location of the transmitter, dynamics variation, noise etc.;

- defining the good algorithm, according to the installation and he data needed for the regulation;

- using the correct adjustments. LP control impacts the LP for only a few degrees and one degree of variation between optimal LP and actual value can strongly reduce energy savings and even, in certain cases, increase power consumption.

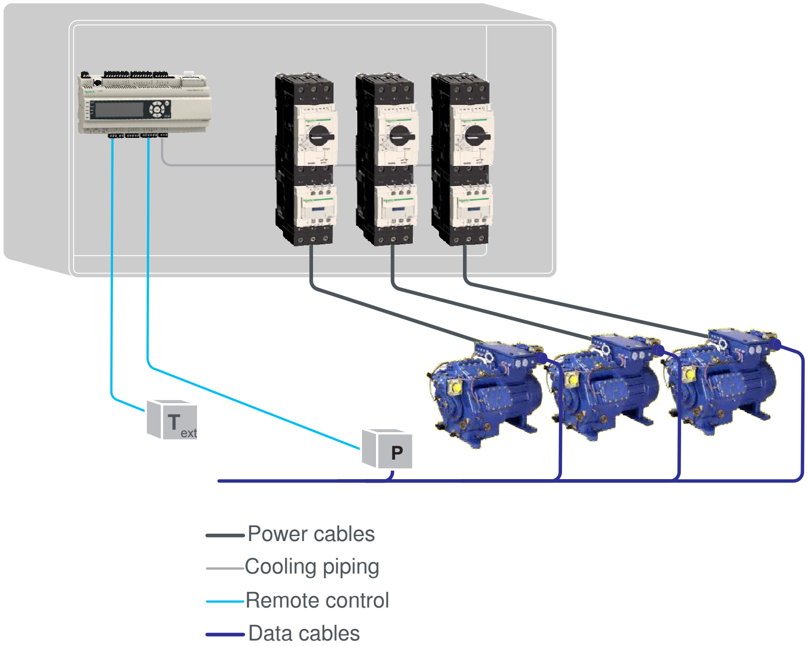


Figure 15 - 3 compressors application

Conclusion

LP control has not been widely used in the past as a solution for decreasing energy consumption. This has been mainly due to the perceived complexity of control. Controllers today have made LP control much easier to implement by the technical community and end users.

Though the LP control solutions is versatile in it's application (from air conditioning to refrigeration systems), it is not a viable application for refrigeration systems where the load is constant. Iice production, gas condensatin, drying, etc.).

In many cases. stand alone applications of LP control is not viable, however, coupled with HP control, LP pressure control is a viable solution and can provide additional energy savings.

It's best to remember that LP control requires proper engineering in order to achieve the best results.

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Document Number WPB5110802EN

7/2011