Energy efficiency with easy advanced control on screw compressors for poultry refrigeration

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Keywords

control, energy efficiency improvements, field factory, measurements, cooling

Abstract

Refrigerating plants are usually controlled with PID controllers. If well set and with no variation in the cooling demand, these PID controllers are efficient. However, these two conditions are rarely combined. Even when equipped with speed variation or head pressure control, refrigerating plants may not be as efficient as they could. EDF Group has developed a new control, based on an internal model of the plant, which anticipates the adjustments of the plant, considering disturbing parameters.

This new control has first been experimented in our laboratory. An energy saving of 11 % has been obtained with a reciprocating compressor and of 15 % with a screw compressor.

This innovation has been tested on the refrigerating plant of LDC, a factory transforming poultry. The Easy Advanced Control has been installed on the 994 kW cooling capacity screw compressors, the cold water pumps and the hot water pumps. The complete energy management allowed to measure an energy saving of 4 %.

Introduction

Refrigerating plants are usually controlled with PID controllers. If well set and with no variation in the cooling demand, these PID controllers are efficient. However, these two conditions are rarely combined. Even when equipped with speed variation or head pressure control, refrigerating plants may not be as efficient as they could. EDF Group developed a new control, based on an internal model of the plant, which anticipates the adjustments of the plant, considering disturbing parameters. This new control is called EAC for Easy Advanced Control.

After having obtained very good results with laboratory tests, the authors tested EAC on an industrial refrigerating plant. The industrial site is a factory transforming poultry from the company LDC, in France.

The presented work compares PID (Proportional Integral Derivative) control with EAC new control developed by EDF on the industrial refrigerating plant of LDC. In this paper, the EAC operating principals are first remained, as well as the first lab test results obtained a few years ago. The refrigerating plant of LDC and its former control architecture are then described. The EAC implementation is explained, and the results obtained on the cooling production and electricity consumption are finally shown.

EAC

EDF (Electricity of France) has developed a new control, called EAC for Easy Advanced Control, and based on predictive-functional control (PFC) (Richalet 1993; Richalet 2004). This new control has been tested on refrigerating plants (Changenet 2008; Fallahsohi 2010a; Fallahsohi 2010b), as well as heaters and heat pumps (Vaudrey 2016) in replacement of the most frequently used control, which is the proportional-integral-derivative (PID). PID may be of good performances if well settled for nominal operating conditions with no disruption from outside the system. But it is not accurate if the refrigerating machine is subject to fluctuations of cooling load or outdoor temperature. EAC method is based on the development of a simplified internal model for a given system. The system can be the expansion valve, the condenser fans, the compressor motor of the refrigerating plant, the chilled water pumps … EAC calculates the response of the system and uses this calculation to adjust the control. The method has been described by Ballot-Miguet 2016. The only parameters the operator has to adjust at the first commissioning are K, the system gain, T_d, the system time delay, and τ, the system time constant. Only 3 parameters to use a predictive control lead to an Easy Advanced Control.

PREVIOUS RESULTS

We previously showed lab results on screw compressors (Ballot-Miguet 2016). Using EAC instead of PID on a lab refrigerating plant, for the same set point, induced a 15 % increase on the Energy Efficiency Ratio (EER).

Plant

LDC is one of the food leaders in Europe. It employs 16,000 people in 67 sites in Europe. Its main activity is poultry production. EAC has been implemented in one of LDC's sites in Bourgogne region, France. This site produces 70,000 chickens per day. The cooling production represents around 50 % of the total energy bill. The site is equipped with 2 refrigerating installations: a reciprocating compressors one and a screw compressors one. We worked on the latest. Figure 1 shows a plan of the installation.

SCREW COMPRESSORS

3 Bitzer screw compressors produce a cooling capacity of 994 kW, with an electric capacity of 464 kW. The working fluid is ammonia. The installation has been built in 2011. It produces cooled glycol water at -8 °C and hot water at 20 °C by heat recovery. Only one compressor is equipped with an electronic variable speed device (VSD).

EXPANSION

The installation is equipped with a float valve, operating by a change in liquid level in the low pressure receiver. Though it cannot be controlled with the Programmable Logic Controller (PLC).

CONDENSATION

The ammonia condensation is done with a water plate condenser. The hot water is used for heat recovery. The lost heat is evacuated with a dry cooling tower. Fans are controlled with a PLC separated from the one controlling the compressors. None of the fans are equipped with VSD. A pump (named condens-

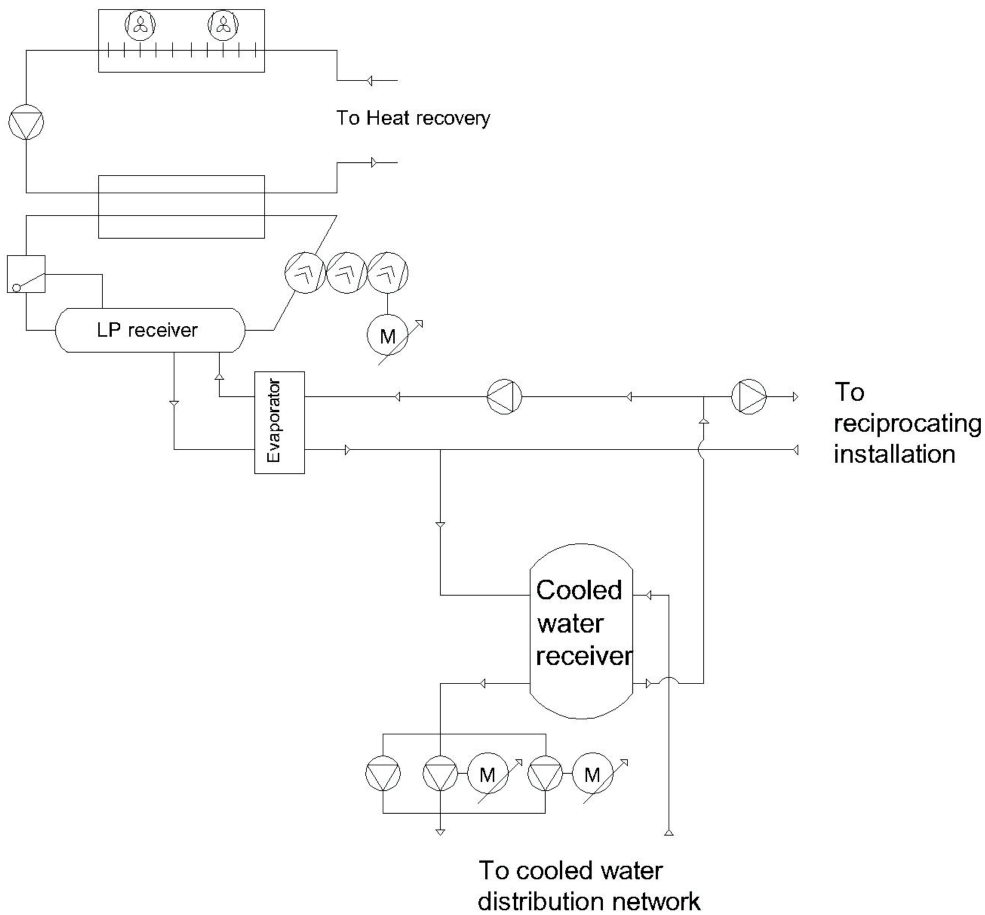

Figure 1. LDC Bourgogne refrigerating installation, screw compressors part.

ing pump) with no VSD allows the hot water circulation to the heat recovery exchangers and the dry cooling tower. High pressure value is constant.

EVAPORATION AND SECONDARY LOOP

The low pressure ammonia comes from the receiver to feed the plate evaporator. The cooled water goes from this evaporator to a cooled water receiver thanks to a primary pump. The cooled water receiver is also fed with cooled water coming from the reciprocating installation. The cooled water circulates from the receiver to the plant with 3 secondary pumps. Two of them are equipped with VSD, but VSD is never used. The pumps are controlled with pressure difference in the cooled water distribution network.

PLC

The Schneider Electric PLC allows the control of:

- Low pressure
- Oil cooling
- Pumps
- Heat recovery

MEASUREMENTS

The refrigerating plant is equipped with full sensors so that the measurements and energy performance calculations can be done and extracted easily. Measurement files are extracted every week.

EAC Implementation

The EAC implementation includes 2 steps:

- We first change the parameters on which the different actuators are enslaved.
- We then change the PID control of 4 actuators with EAC control.

CONTROL ARCHITECTURE

In the first place, the compressors were enslaved to the low pressure value in the low pressure receiver. We now control the speed and numbers of compressors with the cooled water outlet temperature.

In the first place, the primary pump was enslaved to the water flow. We now control the speed of the primary pump with the water flow and the water inlet temperature in the evaporator.

In the first place, the secondary pumps were controlled with the water flow difference between the primary water loop and the secondary water network, and the water pressure in the secondary water network. We still control the secondary pumps with these two parameters, and we added a third parameter: the inlet water temperature to the water receiver.

The condensing pump controls the ammonia head pressure. A VSD has been added to this pump. The water outlet temperature from the dry cooling tower is measured. The ammonia condensing temperature set point is calculated from this measurement, considering a temperature difference of 8 K, respectfully to the design characteristic. Ammonia high pressure is measured real-time, which allows to calculate the real condensing temperature. The pump speed is used in order that the real condensing temperature reaches the condensing temperature set point.

EAC IMPLEMENTATION

The 4 actuators which were moved from PID to EAC are:

- The compressors
- The primary pump
- The secondary pumps
- The condensing pump

The PLC software containing PID control has been modified by replacing the PID equations with EAC equations. The security control has been kept as it was in the first place. The EAC commissioning needs a learning phase during which the control loop of each actuator runs as an open control loop. This phase allows to determine the 3 parameters K, T_d, and τ. The learning phase needs less than one hour for each actuator. The plant continues to run all along the implementation and the learning phase.

Results

Data recordings have been conducted during 2 weeks: week 52-2015 (December 24th to 31st, 2015) during which the refrigerating plant was controlled with PID, and week 9-2016 (February 26th to March 3rd, 2016) during which the refrigerating plant was controlled with EAC. The length of running the plant is the same in both cases. The conditions of recording data are the same. The total production data are displayed in Table 1. The total cooling production is around 50,000 kWh each week. The cooling production of week 9-2016 is lower than the one of weed 52-2015. The EER (Energy Efficiency Ratio) calculation takes into account this difference. The compressors electricity consumption is around 10 to 19,000 kWh each week. The auxiliaries' electricity consumption is around 6 to 9,000 kWh.

The obtained results on parameters (temperature, pressure, flow …) and the refrigerating plant components (pumps and compressors) can be presented in 3 categories explained below.

STARTING THE COMPRESSORS AND PUMPS

While the PID control starts the 3 compressors at the same time, the EAC control starts only one compressor when its capacity is sufficient to produce the cooling capacity. Figure 2 shows the electrical capacity absorbed by each compressor during each week. First we see that EAC allows not to start 2 of the 3 compressors, and second, compressor 1 runs within its capacity range, avoiding to stop. This running allows to extend the lifetime of the compressors and to decrease the electricity consumption.

Concerning the pumps between the evaporator and the cooled water receiver: PID control starts both pumps while EAC starts only one when it's sufficient. The pumps are running or stopped during a long period with EAC, which increase their lifetime. Furthermore, the electricity consumption is much more stable and then reduced with EAC. See Figure 3.

Table 1. Cooling production figures.

	WEEK 52: PID control	WEEK 9: EAC control
Compressor 1: total electrical consumption (kWh)	12,960	10,034
Compressor 2: total electrical consumption (kWh)	3,735	73
Compressor 3: total electrical consumption (kWh)	3,167	129
Total compressors electrical consumption (kWh)	19,862	10,236
Total cooling capacity produced (kWh)	66,665	46,997
Auxiliaries electricity consumption (kWh)	9,603	6,032

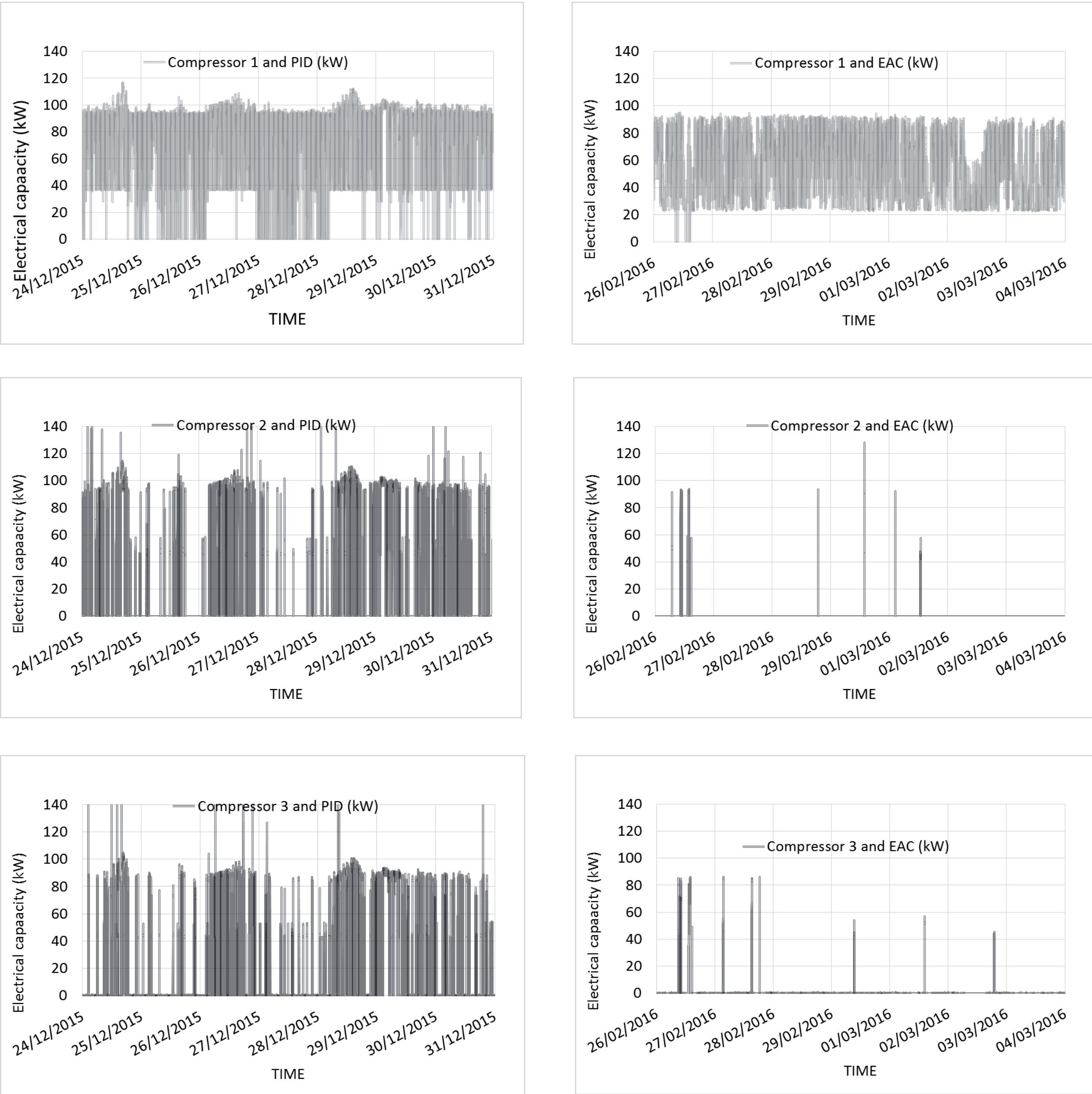

Figure 2. Compressors controlled with PID (left) and EAC (right).

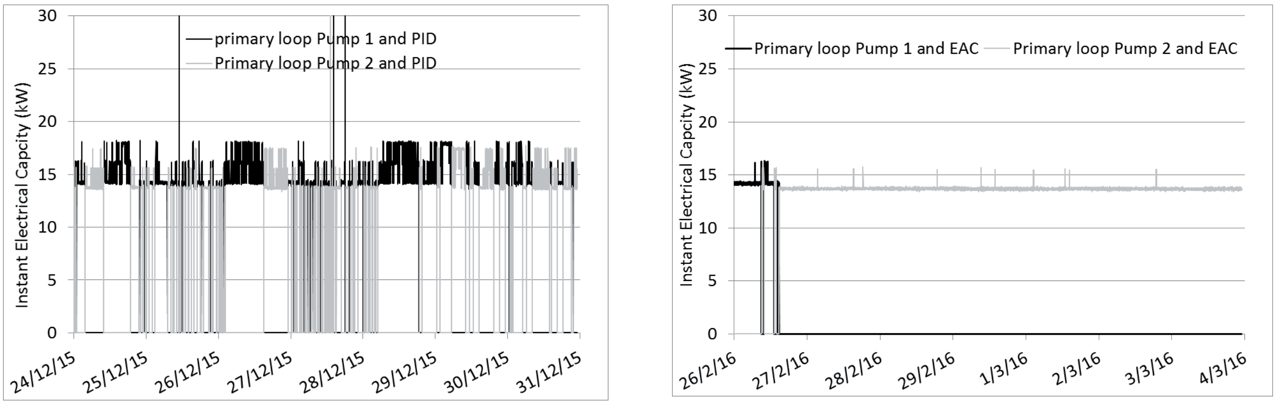

Figure 3. Pumps controlled with PID (left) and EAC (right).

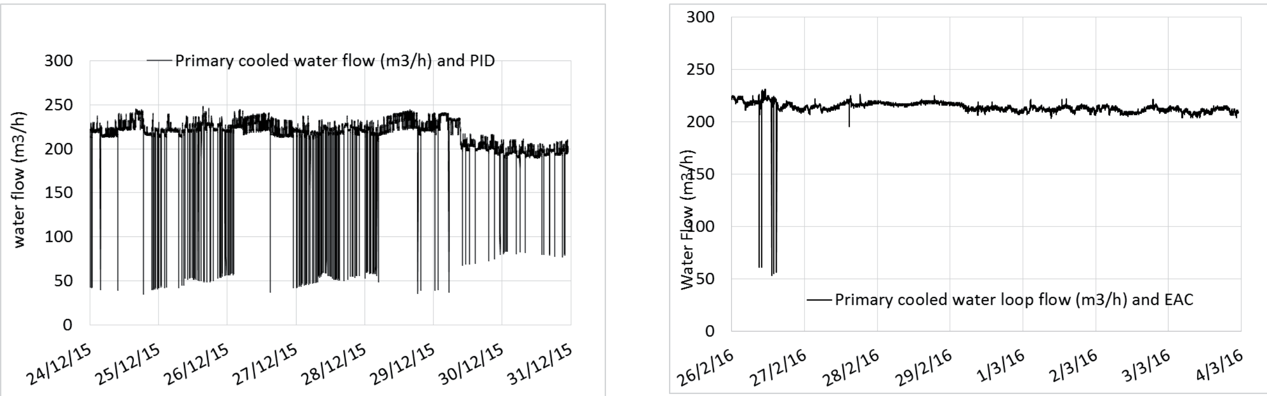

Figure 4. Water flow with PID (left) and EAC (right).

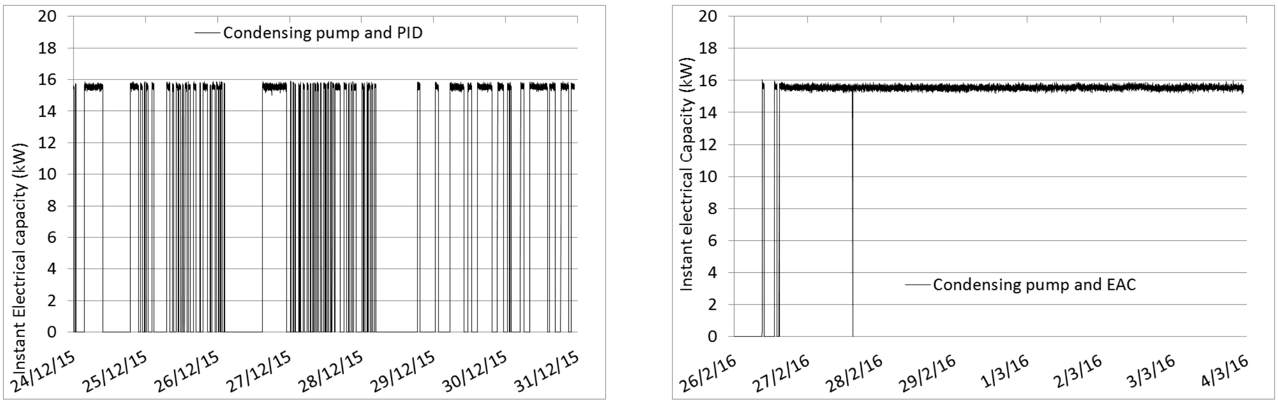

Figure 5. Condensing pump consumption with PID (left) and EAC (right).

BETTER STEADINESS OF THE SIGNALS

The consequence of a better start of the compressors and pumps is a steadiness of the signals. Figure 4 shows the example of the primary cooled water loop driven with the primary pumps. We can see much less fluctuations form very low to high flows, but also much less fluctuations around the set point. Figure 5 shows the electricity input at the condensing pump. Here again, the pump running is much more stable. The consequences are a better steadiness of temperatures and the possibility to increase the evaporation temperature.

EER IMPROVEMENT

EAC improves the performances of the refrigerating plant. This is due to the start and stop control on compressors and pumps, as well as a better control of the temperatures. Ammonia head pressure is shown on Figure 6: a fixed head pressure at 10.5 bar g has been replaced with a floating head pressure. We can notice that the outside temperature during EAC week 9-2016 is lower than during PID week 52-2015. But at the end of week 52-2015, the temperature is of the same order of magnitude than during weed 9-2016, but the head pressure does not decrease, because the PID is a fixed head pressure control. EAC and floating head pressure allow to decrease the head pressure, thus to decrease the electricity consumption of the compressors. One might say that the decrease of the head pressure is only due to floating head pressure control, whether it is controlled with PID or EAC. We have shown in a previous work that the floating head pressure is better regulated with EAC than with PID (Ballot-Miguet 2016).

Table 2 shows EER results. The measured EER are first shown at the average evaporating and condensing temperatures of the recorded week (in the upper part of the table). We calculated 2 different EER: the first one is calculated considering only the electricity consumption of the compressors, and the second one is calculated considering the electricity consumption of the compressors and of the auxiliaries, which are: the primary pumps, the secondary pumps, the condensing pump, the water pumps of the oil refrigerating loop, the dry cooler fans.

In the down part of Table 2, EER have been corrected considering the average condensing and evaporating temperatures. The correction has been done using the ammonia properties, so that the calculated EER are for an evaporating temperature of -13 °C and a condensing temperature of 30 °C.

The compressor corrected EER is 3.4 with PID and 3.8 with EAC, representing an increase of 12 %. The compressor plus auxiliaries corrected EER is 2.3 with PID and 2.4 with EAC, so the increase is of 4 %.

Conclusion

Using EAC instead of PID allows a better stability of the signals (temperatures, flows, and pressures) and a better management of the start and stop of the compressors and the pumps. Combined with existing and new VSD, it increases the EER of a LDC poultry refrigerating plant 994 kW cooling capacity by 4 %. Calculated only with the compressors, the increase is of 15 %. These first results were obtained after only 2 commissioning days, which must be compared to the time needed to configure a complete refrigerating plant whatever the control.

Nevertheless, all signals are not still optimised, so we have to continue to adjust EAC parameters adjustment (the system gain K, the system time delay T_d, and the system time constant τ).

Furthermore, we now plane to work on the fans of the dry cooling tower as well as on the second engine room equipped with reciprocating compressors.

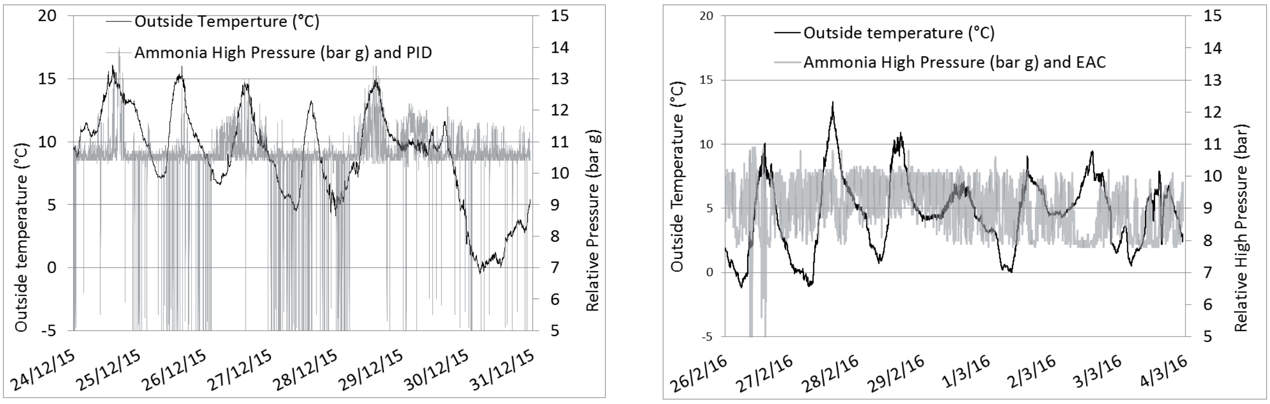

Figure 6. Outside temperatures and ammonia head pressure with PID (left) and EAC (right).

Table 2. EER results.

PID		**EAC**	
Evaporating and condensing temperatures (°C)	Measured EER	Evaporating and condensing temperatures (°C)	Measured EER
-11.4; 29.6	EER on the compressors 3.4	-10.1; 25.1	EER on the compressors 4.6
	EER on the compressors and auxiliaries 2.3		EER on the compressors and auxiliaries 2.9
Evaporating and condensing temperatures (°C)	Corrected EER	Evaporating and condensing temperatures (°C)	Corrected EER
-13; 30	EER on the compressors 3.4	-13; 30	EER on the compressors 3.8
	EER on the compressors and auxiliaries 2.3		EER on the compressors and auxiliaries 2.4

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