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Benefits of integration between heat pumps and food refrigeration systems for commercial applications: an example of efficient energy recovery for Near Zero Energy Buildings

Sergio Maria Capanelli

Carel Industries S.p.A., Via dell'Industria 11, 35020 Brugine (PD), Italy

Abstract

The optimization of energy consumption and the necessity to decrease CO₂ emissions are driving the research of higher efficiency systems for HVAC and refrigeration markets. Introduction of new technologies that have already brought many benefits for residential AC market in refrigeration application and vice versa is an interesting way to increase the general performance of the whole installation. Water loop technology is an example of new development and technology transfer for commercial applications: it achieves the goal to increase cabinet efficiency with different design and the introduction of new technologies like EEV and BLDC compressor. In these plants water loop is also the energy source for the HVAC system in the commercial area. In this scenario, the integration with commercial heat pumps equipped with new generation refrigerant more environmentally friendly like R-744 and the optimization of the whole system are the key factors for an efficient energy recovery system with low consumptions and higher efficiency.

In this work, an example of possible integration is described, where the accurate plant design and the combination of cabinets equipped with Carel HEOS Sistema and a CO₂ commercial heat pump for heating and sanitary hot water production on the same water loop bring benefits for both the unit and the whole building.

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1. Introduction

Nowadays, HVAC and refrigeration markets request more and more new approaches and solutions to reach higher efficiency levels, improve system stability and reduce both energy peaks and waste during the daily operation of the plant. Water loop technology is an interesting example of this trend. This type of solution, already widespread in applications dedicated to residential and commercial air conditioning market, is currently being considered as a very promising possibility to be applied in commercial refrigeration area [1].

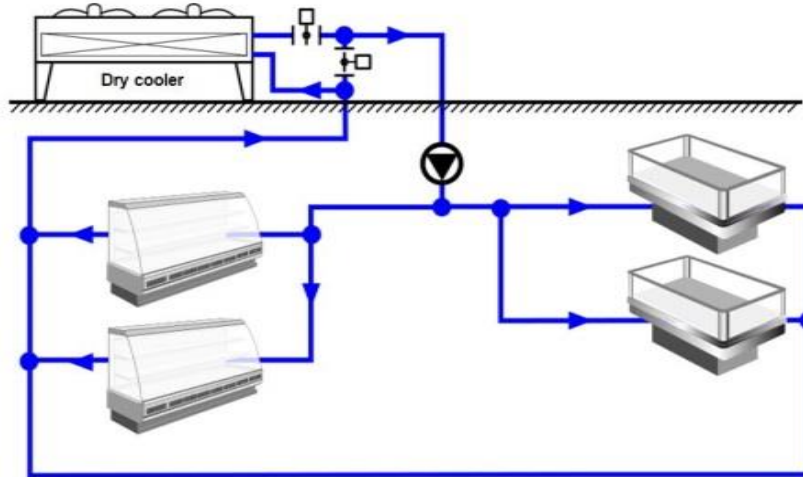


Fig. 1. Example of a water loop system for refrigeration application.

The main benefits from this type of architecture come from an improved stability of the condensation temperature for all the cabinets connected to the loop, increasing the efficiency of each one and reducing in a general way the total cost of the plant, having reduced cost of installation and energy consumption. The idea that CAREL is carrying forward and developing is a further improvement to apply on each cabinet in the line. Each unit is equipped with an electronic expansion valve (EEV) and a BLDC variable speed compressor driven by an inverter.

The EEV permits to control the suction superheat of each cabinet refrigeration circuit: in this way we can control the evaporation and condensation values to optimize the request from the refrigeration side and keep the efficiency of the machine at the most stable level adapting the working conditions at the water loop temperature.

The BLDC compressor allows each machine to be more adaptive, modulating the power according with the request in a more precise way, reducing the number of ON-OFF cycles and optimizing the evaporation and condensation pressure values with two main goals:

- Adapt the compressor working point to the actual ambient condition.
- Maintain the compressor working inside pressure ranges and specifications declared from manufacturer, increasing lifetime and reducing damages occurrence.

The combination of these two high efficiency devices and a dedicated regulation logic integrated inside an electronic controller in each cabinet really lead to a further improvement in terms of efficiency and system stability. The working conditions of the comparison test are shown in Table 1.

Table 1. Comparison between On-Off and BLDC compressor equipped cabinet.

Features	On-Off	BLDC
Nominal cooling capacity	2 kW	2 kW
Compressor maximum cooling capacity	2.4 kW	2.4 kW
Actual cooling capacity	1.5 kW	1.5 kW
Air set point	2 °C	2 °C
Ambient temperature	18 °C	18 °C

Evaporation temperature	-11.3 °C	-5.5 °C
Condensation temperature	28.9 °C	21.2 °C

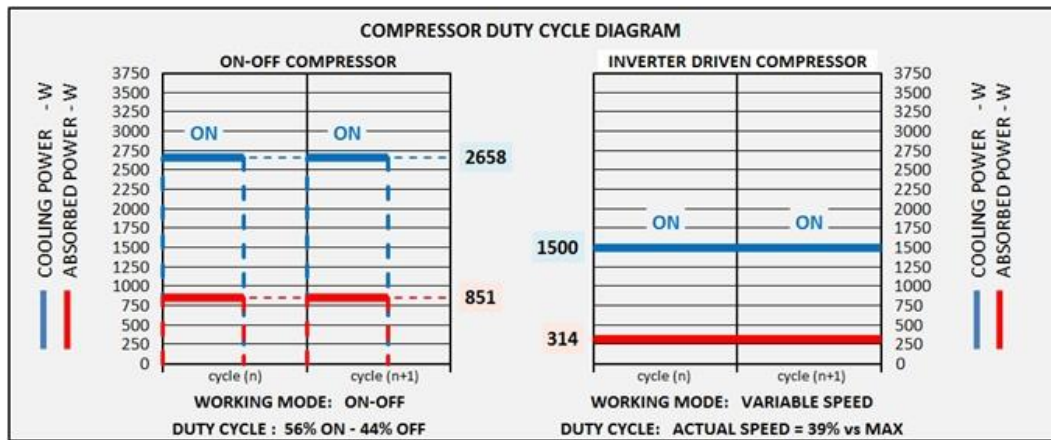


Fig. 2. Comparison between ON-OFF and BLDC compressor performance in a cabinet system.

The estimated energy saving rate is around 35% when comparing the two different technologies, as represented in Fig.2. This paper presents an example of the technology described above, that has been carried out together with one customer for a supermarket installation. In this application, the water loop has been also used as a cold source for a commercial heat pump which use R-744 refrigerant.

2. Plant description

The plant was built in 2016 inside a supermarket in the north of Germany, where the annual average temperature is 8.8 °C. The number of cabinets of each type (low or medium temperature) is shown in Table 2.

Table 2. Number and type of cabinets (R-410 is the refrigerant used).

Type of Cabinet	Number
Low temperature (LT)	17
Medium temperature (MT)	23

The general concept and equipment of the cabinet are shown in Fig.3. The condensation temperature of the cabinet is maintained at an average value of 25 °C, using the cooling effect of the CO₂ heat pump. The values of COP at a condensation temperature of 25°C for different values of evaporation temperature are shown in Table 3.

Table 3. COP cabinet compressor (Toshiba DA130) at condensation temperature = 25 °C.

Evaporation temperature	-35	-30	-25	-20	-10	-7.5	-5	-2.5	0
COP	1.288	1.533	1.863	2.23	3.207	3.523	3.877	4.278	4.736

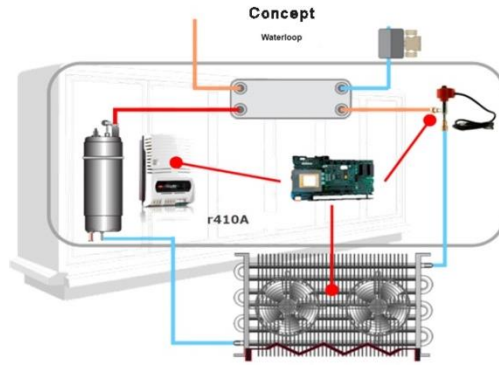


Fig. 3. Cabinet general concept and equipment.

The general schema of the plant is shown in Fig.4. The characteristics of the heat pump / water cooler machine are resumed in Table 4.

Table 4. Heat pump / Water cooler (R-744 is the refrigerant used).

Features	Value	Comment
Cooling Capacity (trans-critical)	90 kW	-
Cooling Capacity (sub-critical)	72 kW	-
Evaporation temperature	4 °C	-
Outlet water temperature (heating)	42 °C	-
Inlet water temperature (heating)	25 °C	-
Water tank with evaporator	700 liters	-
Compressors (Bitzer)	3	1 modulating + 2 On-Off
COP (trans-critical)	2,6	-
COP (sub-critical)	7,8	-

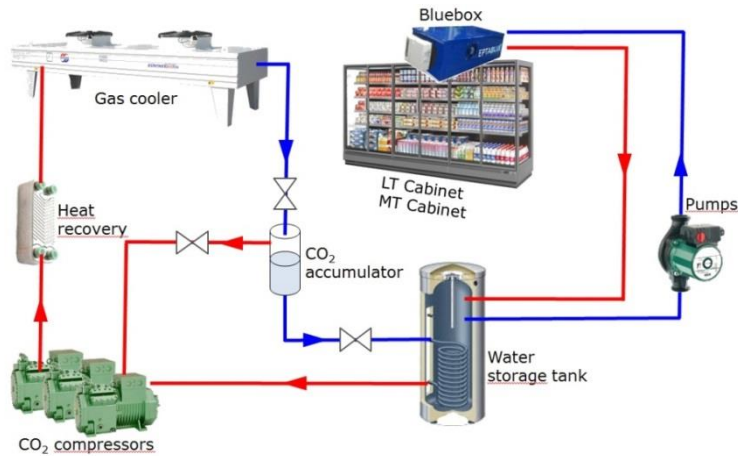


Fig. 4. Plant schema.

Specific data related to gas cooler characteristics and performance are shown in Table 5.

Table 5. Gas cooler (R-744 refrigerant)

Features	Value
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Air volume	37.201 m ³ /h
Cooling performance (trans-critical)	119 kW
Cooling performance (sub-critical)	85 kW
Sound pressure level (at 10 m)	32 dB(A)

The plant has been connected with a supervisory system to keep all the units and the heat pump monitored for data logging and massive test. For example, forcing the switch on/off of the heat pump (or all the cabinets) to test the behavior of the plant in dangerous conditions. Results of this test are shown in Chapter 3.4

3. Test and results

The results of the test performed in the plant are described here below. The first cycle of measurements was made between January and February '16 and the second one was performed in March '16. After the first test session the regulation parameters of the heat pump were refined and tuned in a more precise way to increase the stability and reduce the oscillation, with evident positive effects for all the connected system.

3.1. Water loop temperature

The water loop for the cabinet has been organized in 9 different zones, due to building topology and piping length optimization. The following measurements and data have been measured on zone 6, where the loop 5 cabinet dedicated to milky products is connected. The measurements have been acquired for 24 hours every day, also during closing time on Sunday.

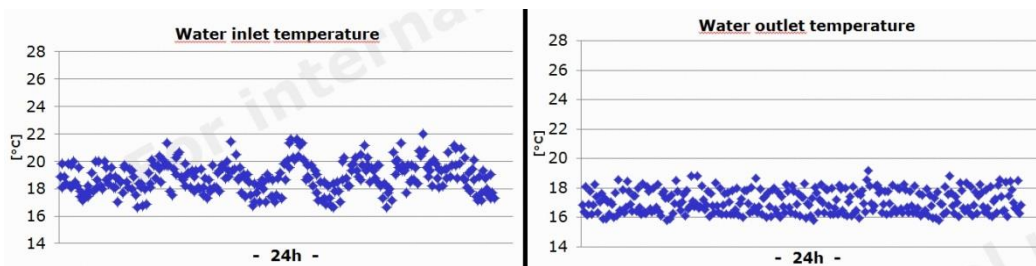


Fig. 5. Water temperature trend on Sunday 24.01.2016 (closing day).

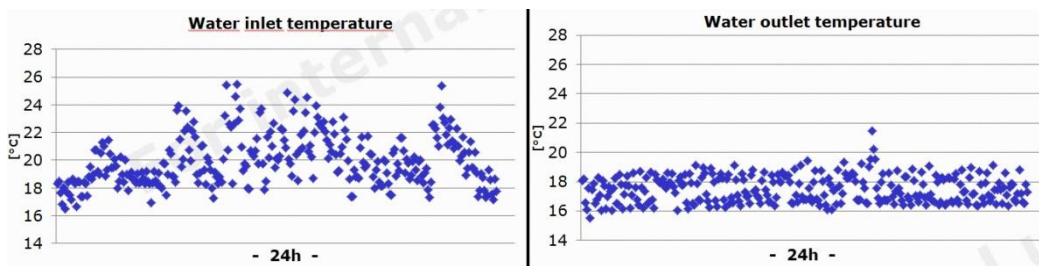


Fig. 6. Water temperatures trend on Tuesday 26.01.2016 (opening day).

As illustrated in Fig.6 and Fig.7, the water temperature is less stable during an opening day due to the continuous variations caused by opening, closing door and variations of the quantity of products inside the cabinets. After an analysis of the data logged during the first cycle of tests, our customer recalculated the parameters for the PID management used for calculation request inside the controller of the heat pump.

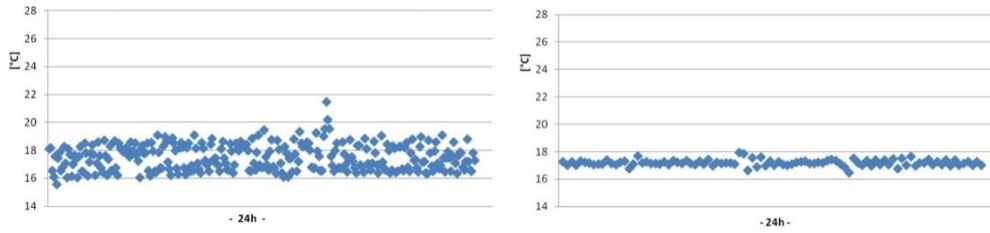


Fig. 7. Outlet water temperature trend on Tuesday 15.03.2016 (opening day) before and after PID optimization.

As shown in Fig. 7, a more stable water temperature in the loop, both in outlet and inlet sides, has a positive effect on the condensation of all the cabinets connected increasing the performance of each single unit, and maintaining the condensation temperature on the project value to keep high efficiency in the system.

3.2. Evaporation temperature (R-744 heat pump/chiller)

The main effect of PID parameters optimization is visible on the evaporation temperature trend, as illustrated in Fig. 8. The main objective of the refined regulation was to control the variable capacity of the first compressor, increasing its reaction time and thus reducing the number of unnecessary switch on and off of the other two On-Off compressors.

The previous setting did not allow the main variable speed compressor to react to the suddenly changes of the water temperature caused by the cabinet performance. Every compressor starts and stops introducing a suddenly change of evaporation. To control this behavior the EEV needs to open or close continuously to keep the superheat values as more close to the set point as possible.

The most stable situation reached after PID set up showed a more efficient behavior of the heat pump, with the following benefits:

- More precise regulation of EEV with strong reduction of range of steps;
- The number of startups of both the second and the third compressor are drastically reduced: in most of the cases the capacity of the variable speed is enough to satisfy the load variation inside the water storage tank.

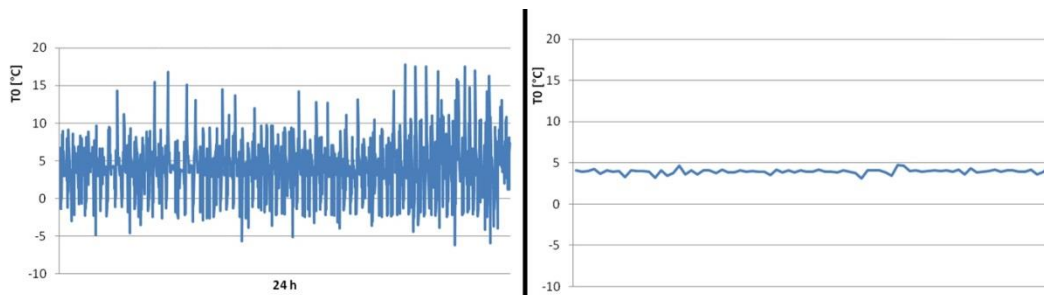


Fig. 8. Evaporation temperature trend in a 24 hours time lapse, before and after PID optimization.

3.3. Energy consumption (R-744 heat pump/chiller)

Linked with the previous consideration about avoiding unnecessary startups of an additional compressor, the total consumption of the unit also have huge benefits. As shown in Fig. 9, the average consumption is reduced by a few percentage points (2-3%), compared to the previous average value of 7.6 kW. The most important benefit comes from the reduction of consumption peaks during the 24 hours of data logging. Indeed, this has been the most claimed behavior from the final customer.

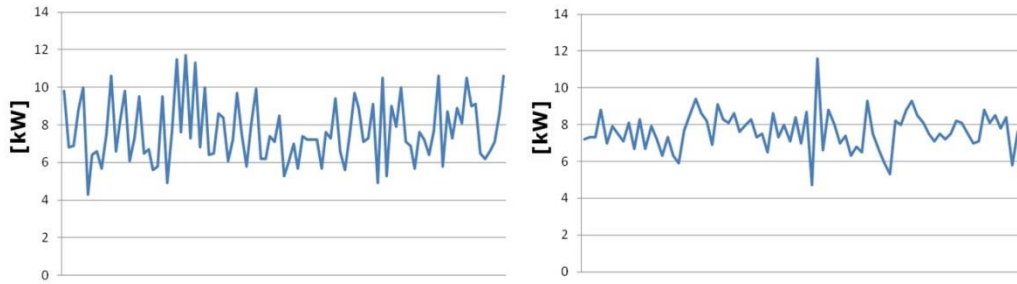


Fig. 9. Energy consumption trend in a 24 hours time lapse, before and after PID optimization.

To sum up, applying the new PID parameters, the trend looks smooth and the customer has been satisfied. The only high peak still present is caused by an automatic maintenance operation performed from the EEV: every 24 hours the valve makes a complete opening and closing cycle to recover possible loss of steps due to continuous regulation over the day without any stop.

3.4. Cooling system failure test (R-744 heat pump/chiller)

A failure test has been performed to monitor the behavior of the system in case of failure of water loop cooling system. The main effect of heat pump/chiller stop is visible on the water temperature trend of zone 6, as illustrated in Fig. 10.

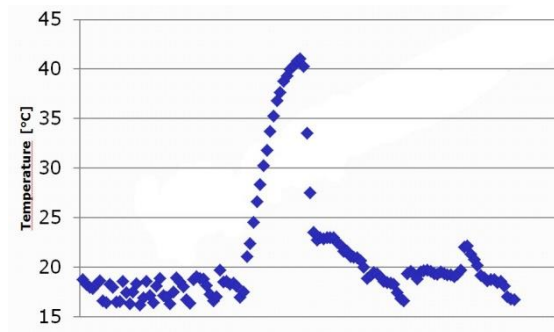


Fig. 10. Water outlet temperature trend during the cooling system failure test.

Specific data related to test characteristics and performed steps are shown in Table 5.

Table 6. Failure test: execution steps.

Time	Description	Water temperature	Comment
10:00	Test starts: the heat-pump chiller is switched off	17.5 °C	-
11:25	Water temperature reaches the peak value	41 °C	-
11:30	First cabinet stops for temperature control alarm	41 °C	In few minutes same alarm occurs on other cabinets.

11:30	The heat pump/chiller is switched on again	41 °C	-
11:50	Water temperature decrease to an efficient temperature level	24 °C	-

To sum up, since the cooling system is switched off, all the cabinets continue to work and the water loop temperature up to reach a critical level in about 90 minutes. When the R-744 unit is switched back on, the time necessary to reach an acceptable temperature level is around 20 minutes.

The results shown that the system is able to support hard working condition for a quite long time. A supervisory system could anticipate the arise of cabinet failures, monitoring the water temperature and informing technical maintenance in advance, helping to prevent failures and cabinet stops.

4. Conclusion

The results of these tests performed on the field show that is possible to integrate an air conditioning system and a refrigeration solution with benefits to both. An important point to emphasize of this case study is the tuning phase related to the heat pump to improve the stability of the unit, assuring a first level integration between the heat pump and the cabinet.

The opportunities to get further improvements in terms of system efficiency, plant integration and emission reduction are many and various. Different proposals are now under evaluation by the cabinet producer and the installer:

- Integration of a supervisory system with a controller dedicated to coordinate the control: instead of waiting for the reaction of the different machines on the field due to changes in working conditions, the controller will have to evaluate the possible countermeasures, modifying set points for temperatures or devices speed. In this way, it would be possible to anticipate the behavior and reduce the peak of consumption and long transitory states.
- Optimization of heat pump performance in partial load conditions: possibility to change the compressor type and configuration to better adapt the machine to the working conditions defined by supermarket users and ambient conditions.
- Use of green refrigerants in the cabinet: a project is currently under development, whose objective is to create a similar plant with all the units equipped with R-744 refrigerant, reducing the total global warming potential (GWP) of the refrigerants used in the plant.

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