Seasonal energy efficiency (ESEER) of different installation solutions of chillers using screw compressors for R134a

UNIVERSITY OF STUDIES OF PADUA :

Prof. Eng. Ezio Fornasieri, Dr. Eng. Marco Corradi, Dr. Eng. Luca Cecchinato.

BITZER ITALIA Srl:

Eng. Pietro Trevisan

1. Introduction

In the past few years, energy efficiency has adopted a fundamental importance in the evaluation of different technologies applied to air conditioning. Until now, the matching of the screw compressor with the R134a is doubtlessly one of the best compromises for efficiency, operational flexibility and reliability in making water refrigerators.
Different installation solutions of screw compressor chillers were examined to determine which one was the most efficient.

2. The ESEER parameter (European Seasonal Energy Efficiency Ratio)

Liquid refrigerators, more commonly called chillers, are usually used at their maximum power for only a limited period of time in a year. That is why performance and efficiency in partial load conditions are surely a much more representative parameter for the evaluation of unit energy consumption per year.
This is why a number of seasonal efficiency indexes were introduced to make the comparison of annual energy consumption of different unit easier.
Among these indexes, the most known and used are the IPLV –Integrated part load value-, applied mostly in the Northern American market and the ESEER –Seasonal energy efficiency ratio– usually used in Europe.

The IPLV and ESEER values are obtained as the weighed mean of efficiencies (EER) realized by chillers at the various load nominal steps (25%, 50%, 75% and 100%). The following formula defines the calculation mode of the ESEER parameter:

$$ESEER = A \times EER(100\%) + B \times EER(75\%) + C \times EER(50\%) + D \times EER(25\%)$$

The fundamental hypothesis of these simplified comparison methods is that the thermal source temperature for the condensation varies according to a pre-determined mode with the load (see the following Table 1, which shows the ambient temperatures to adopt in the various load steps and the weights to be used in the mean calculation).

Table 1: Ambient air temperatures to be considered at the different load steps of air cooled chillers and weights to assign to the EER values made by the chillers in the same steps

	ESEER Parameters	
Part Load Ratio	**Air Temperature (°C)**	**Weighting coefficients**
100 %	35	3% = A
75%	30	33% = B
50%	25	41% = C
25%	20	23% = D

In this analysis, a few aspects that affect the ESEER value of air condensed chillers equipped with a compact screw compressor for R134a will be examined.

3. Schematization of the chiller and boundary conditions.

In the simulations, we will assume to consider a dual circuit chiller, meaning the chiller is equipped with two separate circuits, each one of them made up of the following :

- BITZER CSH8591-140Y screw compressor
- R134a refrigerant,
- condensation section made up of finned coils,
- axial fans (4 impellers D=800mm for each circuit),
- shell and tube (dual circuit) evaporator,
- expansion valve.

To help make the discussion clearer, when a load step (100%, 75%, 50%, 25%) is mentioned, we will also specify if it is meant as a total power step of the chiller or as of a single compressor.

The working conditions taken as input data for the calculation are specified by EUROVENT for the ESEER evaluation:

- the air ambient temperature in the different load steps as in Table 1.
- at 100% of the load, the water temperature entering the chiller is +12°C.
- the water temperature at the evaporator outlet is +7°C in all load condition.

The condensers are dimensioned with deltaT=15K, compared to the 100% air input temperature. The evaporator is dimensioned to obtain deltaT=5K on output water. The liquid subcooling is taken to zero K and the suction gas superheat is equal to 10K in all operational conditions.

4. ESEER calculation

The most important chiller component to determine the ESEER is the compressor. Modern compact screw compressors equipped with a slide valve allow stepless or stepped regulation of the generated suction volume and consequently the regulation of the cooling capacity supplied to the user. An aspect that should be considered carefully is the definition of the cooling capacity management logic of the compressors to obtain the best overall efficiency of the chiller. That is, it's important to ask questions such as: Does the chiller have, operating at 25% of the load, a higher efficiency if 2 compressors at 25% are used or if only one is used at 50%?

Within the installation solutions and operational reference conditions described in paragraph 2, the numerical processing gave the following results:

Table 2: the EER and ESEER values for dual circuit chiller with screw compressor (each circuit is equipped with its own condenser). The 25% load step of the chiller is made with two compressors at 25% load.

Chiller with two circuits and one compressor per circuit				
chiller Load %	100	75	50	25
compr. Load step %	2 x 100	2 x 75	2 x 50	**2 x 25**
Qo (kW)	541,8	406,3	270,9	135,4
Pel_compr (kW)	180,9	91,9	56,9	28,6
Pel_fan (kW)	12,6	12,6	12,6	6,5
EER_compr.	2,995	4,422	4,760	4,743
EER_chiller	2,800	3,889	3,898	3,859

ESEER_compr. =	**4,592**
ESEER_chiller =	**3,853**

Table 3: the EER and ESEER values for dual circuit chiller with screw compressor (each circuit is equipped with its own condenser). The 25% load step of chiller is made with only one compressor at 50% load.

Chiller with two circuits and one compressor per circuit				
chiller Load %	100	75	50	25
compr. Load step %	2 x 100	2 x 75	2 x 50	**1 x 50**
Qo (kW)	541,8	406,3	270,9	135,4
Pel_compr. (kW)	180,9	91,9	52,6	24,5
Pel_fan (kW)	12,6	12,6	8,8	4,3
EER_compr.	2,995	4,422	5,154	5,535
EER_chiller	2,800	3,889	4,413	4,701

ESEER_compr. =	**4,935**
ESEER_chiller =	**4,258**

Note 1: the EER_compr and ESEER_compr values are calculated with consideration to the electrical power absorbed by the compressors (not by the fans); when the EER_chiller and the ESEER_chiller are calculated, the sum of the electrical power absorbed by compressors and fans is considered .

Note 2: Tables 1 and 2 were calculated by using the calculation method suggested by EUROVENT. In the event, very often in practice, that the chiller can not exactly supply the pre-set nominal load steps (100%, 75%, 50%, 25%), this method recommends to linearly interpolate between the first step above the nominal step and the first step below it. In this analysis, to simulate the 25% nominal step of the chiller, we interpolated between the 25% step of the chiller and the condition when the chiller is off. Tables 1 and 2 show that, the more the chiller load reduces, passing from 100%, to 75%, to 50% and to 25%, the more the EER value increases (and that is logical, since, when room temperatures decrease, condensation progressively lowers and the overall efficiency of the refrigerating cycle increases). The reading of the ESEER values in the two application cases shows that the most efficient regulation is shown in Table 3.

In this first calculation example, we assumed that all fans were working as well as the compressors. Moreover, the analysis shows that the ventilation load on the ESEER value can not be considered as marginal. Therefore, a fan management logic should be studied to optimize the seasonal energy efficiency of the refrigerator.

5. ESEER variation with different ventilation control logic.

In this second part of the analysis, we assumed that we'd be able to regulate the ventilation section. Therefore, to make it simpler, we assumed an on/off regulation of each fan that must be carried out with proper gravity shutters to prevent the air recirculation though fans switched off.

Therefore, the calculation of the previous paragraph was repeated and we tried to maximize the EER value of each chiller step by varying the number of operating fans.

Table 4: the EER and ESEER values for dual circuit chiller with screw compressor (each circuit is equipped with its own condenser). The 25% load step of chiller is made with only one reduced compressor at 50% and three running fans out of four.

Chiller with two circuits and one compressor per circuit				
chiller Load %	100	75	50	25
compr. Load step %	2 x 100	2 x 75	2 x 50	**1 x 50**
Qo (kW)	541,8	406,3	270,9	135,4
Pel_compr. (kW)	180,9	91,9	53,8	25,8
Pel_fan (kW)	12,6	12,6	7,9	3,2
EER_compr.	2,995	4,422	5,034	5,244
EER_chiller	2,800	3,889	4,390	4,665

ESEER_compr. =	**4,819**
ESEER_chiller =	**4,240**

The ESEER value obtained with this simulation (with capacity regulation based on fans on/off) is just little lower than the previous case. Probably, by equipping the chiller with a finer regulation of air capacity, the ESEER value could be increased compared with the case of the table 3.

6. The ESEER variation with different finned coil condenser circuitation .

In the examples we have evaluated up to now, we have always considered to have physically separated and independent condensation batteries for the two circuits. That means that, when only one of the two condensers is operating (this is the most efficient solution to obtain the 25% load step of the chiller), only half of the condensation area installed on the chiller is used (in fact, the condenser of the compressor that is not operating is inactive).

The following point was to assume to use finned coils with interconnected circuits.

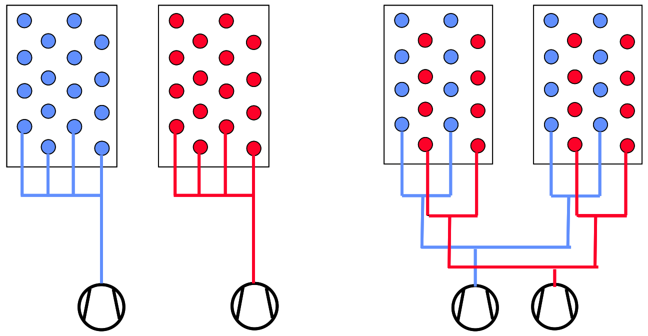

Figure 1: Simplified schematization of two different types of circuitation:
on the left : completely separate condensers;
on the right: interconnected circuits on both coils.

The goal of this unusual circuit layout is to use the fins of both coils, even when only one compressor is active, but the two circuits from the refrigerant fluid side are kept separate. This allows for taking full advantage of the available exchange area and for maintaining all, or at least a few, of the fans relevant to the finned batteries.
Therefore, we have to evaluate if the bigger available heat exchange surface, compared to the traditional case, offers a bigger efficiency advantage than the increase of electrical power of the fans.

Moreover, the solution under examination implies a decreasing of the efficiency of each fin and consequently of the entire exchange surface. That is why the feeding of half of the circuits causes the rise of the characteristic parameter associated with the fin dimension and, therefore, from this theory we deduct a decreasing of the fin efficiency (see "*Trasmissione del calore*", pages 72-78, C. Bonacina, A. Cavallini, L. Mattarolo, Cleup editore, 1992).

Since the parameter linked to the fin dimension can not be determine precisely, the classical analytic analysis can not be used. Therefore, we used an analysis software on the finite elements that is able to calculate the thermal flow exchanged by the fin and its efficiency after the boundary conditions are defined. The efficiency η of a fin is defined as a ratio between the effectively exchanged thermal flow and the thermal flow that is ideally exchanged by a fin with a thermal conduction at infinity. The so defined efficiency does not depend on boundary temperatures of the system. The assumptions relevant to the simulation are coherent with those that are used in the traditional analysis that are uniform temperature of the air, uniform convection coefficient (according to the number of the operating fans) and uniform temperature of the tubes. The fin thickness was 0,15 mm. In the event of non-powered circuits, the relevant tubes were considered as adiabatic tubes. The numerical analysis results are shown in Table 5.

Table 5: numerical analysis results

Number of fans per battery	**alfa** [W/(m²K)]	η **All powered circuits** [-]	η **Half powered circuits** [-]
4	79.9	0.80	0.58
3	69.0	0.82	0.61

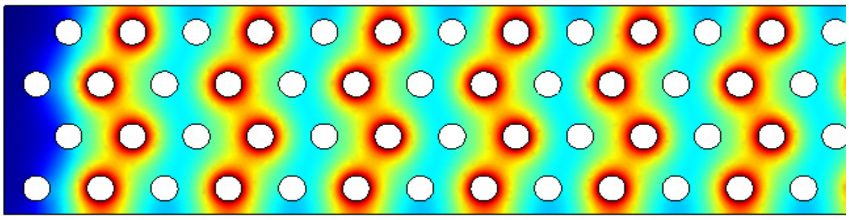

Figure 2: Temperature distribution on the finned area in relation with the numerical analysis developed in the case of interconnected circuits and only one operating compressor.

Table 6: the EER and ESEER values for the dual circuit chiller with a screw compressor. The coils use interconnected circuits. The 25% load step of the chiller is made with only one reduced at 50% load and six running fans out of eight.

Interconnected coil design				
chiller Load %	100	75	50	25
compr. Load step %	2 x 100	2 x 75	2 x 50	**1 x 50**
Qo (kW)	541,8	406,3	270,9	135,4
Pel_compr. (kW)	180,9	91,9	50,8	22,8
Pel_fan (kW)	12,6	12,6	10,4	6,1
EER_compr.	2,995	4,422	5,330	5,939
EER_chiller	2,800	3,889	4,424	4,691

ESEER_compr. =	**5,100**
ESEER_chiller =	**4,260**

This last case allows to make a much higher ESEER value for the compressor and an overall ESEER value of the chiller, which is a little higher to the value obtained in the previous cases. Therefore, the solution with interconnected circuits is the most efficient solution among the analyzed ones.

7. Conclusions

This analysis has allowed for the evaluation of energy efficiency made by the chiller equipped with screw compressors and air condensers for two different circuitations of the coils and a different number of operating fans. The energy efficiency was evaluated according to the ESEER parameter.

The obtained results make us affirm that the energy efficiency is affected by the efficiency of single components used (such as compressors, exchangers, fans, etc.) and also by the regulation logics and operating modes of compressor, fans and finned coils in the different load conditions. In particular, a regulation logic of the compressors was defined, which optimizes the chiller efficiency at partial load. Moreover, the energy efficiency of the traditional circulation solution is slightly worsened in the passage from the use of all fans to the use of 3 out of 4 fans per coil, whilst in the interconnected circuits configuration, if a fan is switched off, the system efficiency increases. Considering that, with this last solution, the increasing of the compressor efficiency is partially frustrated by the relevant increasing of the electrical power used for ventilation, we assume that more reassuring results should occur with more efficient fan capacity controls at partial load such as the rotating speed regulation. In fact, we noticed that the system used in this analysis (some fans were stopped), presents a ventilation power reduction much lower than the theoretical value calculated according to the product of the volumetric capacity per prevalence: that is the consequence of the work point of the characteristic curve of the fan close to the maximum capacity conditions.