White paper

Seasonal performances and compression technology

In the near future, the seasonal performance of thermodynamic systems will be the main performance objective of manufacturers all over the world. In accordance with the logical evolution of the energy consumption of our societies, measurement standards and subsequent labels are coming into a phase of maturity with regard to seasonality.

A theoretical comparison of the different compression technologies applied to a reference installation helps us to make an assessment of the possible benefits of a yearly approach for hot and cold climates. In this example, there is a seasonal COP gap of up to 54%, depending on the compressor technology chosen.

By Jean de Bernardi[1] and Jean-François Le Coat[2]

Background of air conditioning measurement standards

The pioneers in this domain were the US during the 1980s. They established the 3 main founding measurement standards which have been guiding our profession for the last 30 years. The first of these was the ARI 210/240 introduced by the US Department of Energy (DOE) which included for the first time the concept of seasonal COP as applied to the most popular local domestic units (air conditioning units-air/air-12/19 kW, and packaged centralised systems). Three new parameters were in fact introduced at this time. These were the SEER for the cooling mode (Seasonal Energy Efficiency Rating), the HSPF for the heating mode (Heating Seasonal Performance Factor) and the APF which constitutes an annual summary of the two preceding parameters (Annual Performance Factor). At this stage, capacity variation has not been taken into account.

The ARI (Air-Conditioning and Refrigeration Institute) then introduced the ARI 340/360 in response to the need for a measurement standard for larger air/air air conditioning units of over 19 kW, by at the same time creating a first coefficient allowing for the adaptation of the need to the demand to be taken into account with the AIR IPLV (Integrated Part Load Value).
The only thing missing was a measurement standard for water systems. The ARI remedied this situation by introducing the ARI 550/590 for air-cooled or water-cooled water chillers. It then made sense to consolidate an AIR IPLV and introduce a WATER IPLV.

It was only in 2004 that other parts of the world decided to adapt these 3 large US standards to local applications, in particular by taking into account climate differences and the most popular systems in each geographical area.
This is what EUROPE has done with the EUROVENT standard which was mainly built on the foundations of the ARI 550/590 for air-cooled and water-cooled water chillers. A COP exclusively for the cooling mode was introduced: the ESEER based on the WATER IPLV.
Japan and Korea reacted at the same time and were inspired by the ARI 210/240 for domestic air/air reversible systems (<10 kW) and compact units (10 to 28 kW). They made two seasonal performance criteria available to manufacturers: the SEER and the HSPF.

China waited until 2006 to adapt the ARI 340/360 within the framework of air/air exchanges, for either compact units, multi-split units or VRV (Variable Refrigerant Volume) systems. A new annual COP based on the AIR IPLV then emerged.

Labelling, measuring standards and impact on sales

The energy labels which are applied to air conditioning systems all rely on measuring standards to define a performance scale. Therefore it follows that, depending on the standard chosen, which in turn depends on the geographical area, the labels mainly concern the cooling mode, while few of them take into account the heating and cooling modes.

Although energy labels were initially used on a voluntary basis, they are increasingly becoming mandatory all over the world. Some additional voluntary labels also exist to distinguish the best products (for example the Energy Star label in the USA identifies heat pumps which are 8% more energy efficient than the market average, and 20% more efficient than the models installed). The figure below gives an idea of the main labels encountered in daily life.

[1] *Application Engineering Manager, Danfoss Commercial Compressors BP331 01603 TREVOUX*
[2] *Applications Expert, Danfoss Commercial Compressors BP331 01603 TREVOUX*

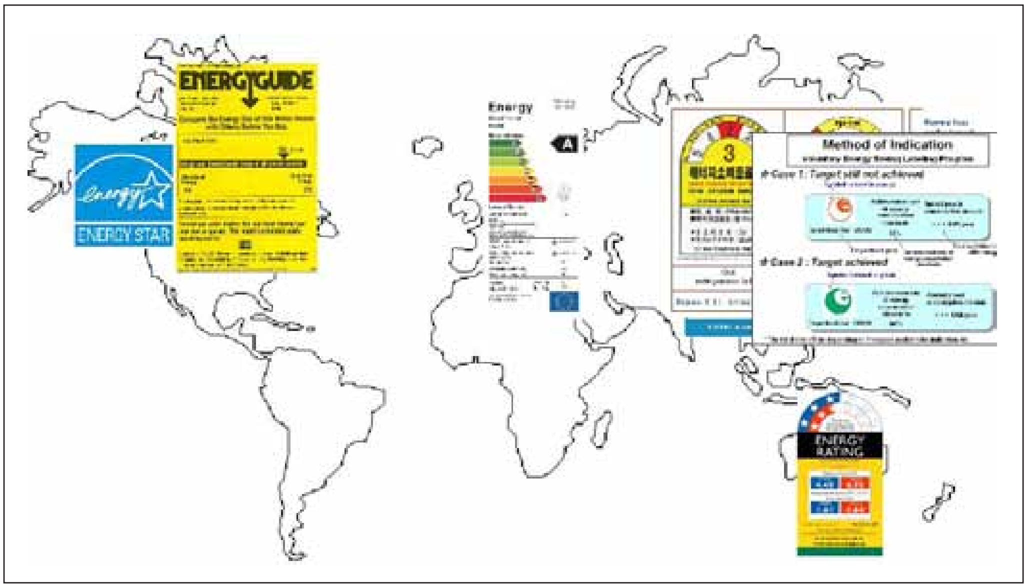

Figure 1: *Examples of energy labels across the world.*

The impact of labelling on energy consumption habits has been studied in the context of the appearance of energy classes on refrigerators in Europe in the 1990s: in around 10 years, European refrigerator sales have progressed from patchy distribution to a market which is concentrated on the most efficient selection. Labelling is therefore a clear purchasing factor for the best systems.

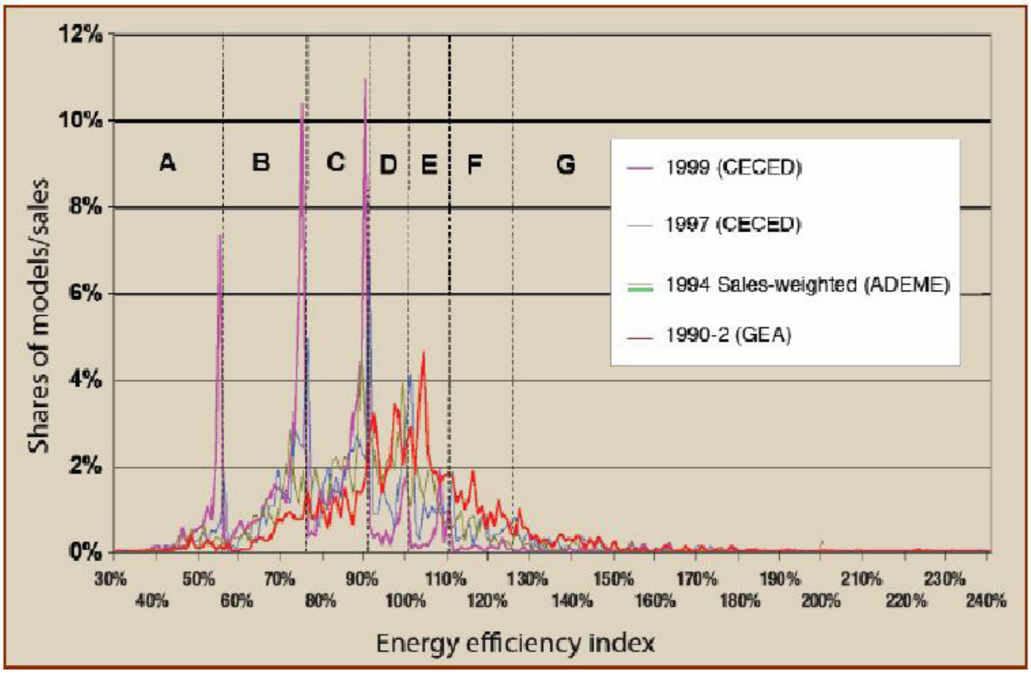

Figure 2: *Impact of energy labels on refrigerator sales in Europe.*

Expected future of measuring Standards and labels

Faced with diverse measuring standards all over the world, a process of harmonisation is underway, with a European proposal which should come into being in 2010 with the review of the CEN/TS 14825 which will apply to the heating and cooling modes, for all applications (air/air, air/water, water/air and water/water) and to all capacities. It will take into account the specific temperatures of the different terminal units as well as varied sources.
In the USA, the CHILLERS ISO, which applies only to the cooling mode, is based on a global climate zoning, on the IPLV and the ESEER.
The corresponding energy labels should follow and ultimately take into account the seasonality associated with the variation in the capacity of the system according to the actual need.

Based on this outline of the past and the future, and without considering the problem of the choice of the refrigerant (which would merit a separate article), it is important to look at the issue of optimising the system so as to obtain the best actual seasonal performance, independently of any measuring standard or label. It is clear that, even if efforts are made so that future standards represent the diversity of the reality of the field as faithfully as possible, an annual approach is the only way of knowing what the electrical consumption saving will be from one machine architecture to another. Consequently, this analysis must be made using an annual charge scenario which directly depends on the application and on the local climate.
The end-user can then, by way of this new approach, equip itself with facilities which will provide the best return on investment. Consequently, annual electrical consumption would replace the COP at several operating conditions as the major argument in selecting and selling.

While it is easy to measure the electricity consumed on-site a posteriori, obtaining an annual predictive COP is a complicated task. However, this is key to the design and selection of components which are adapted and are relevant to the optimisation of the final application.

Currently, there are several solutions available to optimise a system for an annual operation whose main characteristic is the fluctuation of charge over time:

- To begin with, thermal exchange coefficients at evaporator and condenser side may change and adapt to the instantaneous power, using a frequency variation on ventilators in air/air machines or on the circulation pump in exchanges with water.

- Expansion device is a significant problem, as it is necessary to use components which can maintain a stable setting of superheat while undergoing strong capacity changes, particularly during partial load operations, which is often the case with the annual scenario.

- The OFF period consumption levels must be minimised as much as possible and they are directly linked to the selected compression technology. For example, the selection of low-power crankcase heaters may have a significant impact on annual electricity consumption, which is in fact a major component whose selection was relatively neglected in the past.

- There are several possible options to adapt the capacity of compressors to the needs of the installation. We shall limit ourselves here to single-stage systems as a primary approach.
  - The simplest method is to stop the compressors when the temperature requirement is reached and to restart them when the request reappears (ON/OFF system). In this case, the use of several compressors assembled in parallel allows for an additional modularity of power which can be fine-tuned by increasing the number of compressors.
  - A second principle is to by-pass some of the compressed gas and to discharge to the compressor inlet so that the condensation side sees only a fraction of the thermal power produced. This by-pass can be undertaken in 3 main ways:
    1. External by-pass of hot gases.
    2. Internal by-pass of hot gases.
    3. Modulation of capacity by Intermittent Compression IC (similar to Digital technology).
  - Another approach is that the compressor only produces the actual requirement of the installation and therefore only consumes the reduced fraction of electricity which is necessary for this production. This is the choice made by variable speed compressor manufacturers using variable frequency control.

- The compressor can therefore be perfectly optimised for specific application. Its built-in compression ratio can be beneficially increased or decreased depending on the desired final temperature and the climate the system is used in.

DANFOSS has recently developed a thermodynamic systems software approach which allows a precise analysis of the seasonal performance of a system to be made for different charges. Here we are proposing to compare different design options, based on some of the possibilities mentioned previously, and to estimate their respective impacts on the performance of a water chiller. The system described is a single-stage one and OFF period consumption is not taken into account in this example. The compressors used in the simulation are all from the DANFOSS portfolio or they are design modifications whose performances have been validated by lab trials.

Units compared

They are air cooled chillers which operate with R410A and by air condensation. They are equipped with scroll technology compressors.

COMPRESSOR	CAPACITY EN12900 / HBP	MAIN ARCHITECTURE CAPACITY VARIATION
15 TON	39.1 kW	1 circuit / 1 FS (ON/OFF)
2 X 7.5 TON	39.7 kW	2 circuits / 1 FS per circuit (ON/OFF)
DUO 7.5 TON	39.7 kW	1 circuit / 2 FS in parallel (ON/OFF)
VSH 117	48.6 kW	1 circuit / 1 VS (Variable speed)
15 TON IC	39.1 kW	1 circuit / 1 IC (Intermittent compression)
VSH 117 2nd generation PM	49.6 kW	1 circuit / 1 VS

FS: fixed speed compressor *VS: variable speed compressor*
IC: intermittent compression *PM: permanent magnet motor*

The "15 TON" model was taken as a reference for comparison.

Method

The 6 configurations of water chillers are compared in the context of their use under two very different French climates which seek to demonstrate the impact of the local climate on the choice of compression technology when it comes to optimising seasonal performance.
The hottest climate chosen is that of Marseilles and the coldest is that of Nancy.
A complete year of operation was simulated for each unit. The same annual thermal load profile, the same climatic conditions and the same operation parameters were used in all simulations.
Each simulation was made on an hourly basis by making calculations under stabilised conditions for each hour of the year.

The calculations, made for each capacity stage, take into account the limited capacity of the condenser and the evaporator, and allow for different evaporation temperatures in different circuits.

Two series of simulations have been produced with and without speed variation to the condenser fans. These comparisons allow us to contrast the impact of the compression process and the variation of thermal exchange to the condenser to be able to identify the best technical-economic compromise.

Operating conditions

The annual load bar charts are shown in figures 3 and 4.
The condensing temperature varies with climatic conditions and is fixed at 12K above the ambient temperature. Its minimum was fixed at 30.0°C.

The dry ambient temperature was used. The water temperature was kept constant at 7°C. A constant superheat of 6K and sub-cooling of 3K were specified.

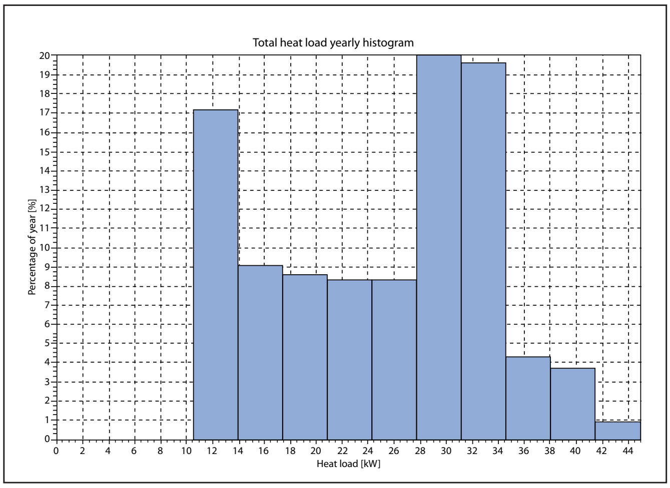

***Fig. 3:** Thermal load in Marseilles*

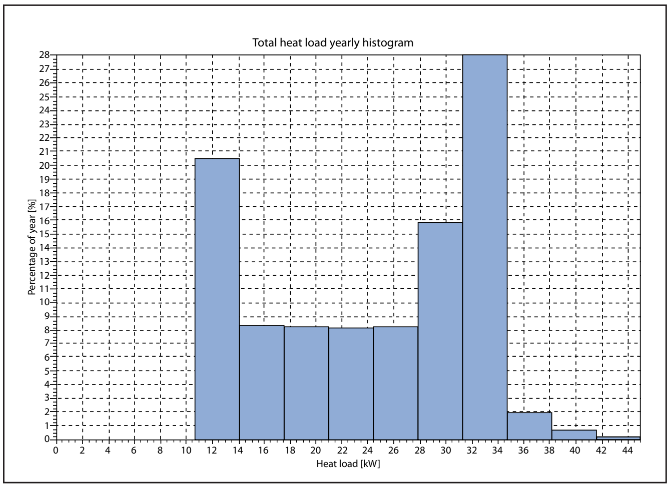

***Fig. 4:** Thermal load in Nancy*

Influence of compressor choice

The two tables below summarise the results of the calculations for the reference water chiller under both climates and for each compression technology option:

	15 TON (Reference)		2 X 7.5 TON		DUO 7.5 TON		VSH117		15 TON intermittent		VSH117 2^{nd} generation PM	
	Mars	Nanc	Mars	Nanc	Mars	Nanc	Mars	Nanc	Mars	Nanc	Mars	Nanc
Annual consumption [kWh]	48720	44447	49599	45209	47341	42942	48645	44077	50974	46884	37969	34137
Annual energy savings [kWh]	0	0	839	761	-1379	-1505	-75	-370	2254	2437	-10751	-10310
Annual gains [%]	0.0	0.0	-1.7	-1.7	2.8	3.4	0.2	0.8	-4.6	-5.5	22.1	23.2
Annual COP	4.48	4.78	4.41	4.70	4.61	4.95	4.49	4.82	4.28	4.53	5.75	6.22

Table 1: *Comparative results in Marseilles and Nancy*

- The first observation concerns the influence of the climate on the performance of the installation. In this application, the system in Nancy seems t o have, on average, an electricity consumption level 10% lower than that observed in Marseilles. This difference arises irrespective of the compressor technology used or the management of the condenser exchange (see table 2). This effect is mainly linked to the load but also to the lower average condensing temperature in a cold climate.
- In this simulation, the intermittent compression technology does not reach the seasonal performances of the ON/OFF capacity variation. The main reason is that the performance level of the compressor falls when internal leakages occur.
- We can observe a 5% difference in performance between a 2 circuit machine (each one equipped with a 7.5 TON compressor) compared to a single-circuit system integrating the same 2 compressors in parallel. This difference is due to the numerous phases of partial running of the DUO, during which the exchangers are oversized, hence improving the thermal exchange coefficient.
- VSH117 is, in this air cooled chiller application, equivalent to DUO.
- The case of the variable speed compressor VSH117 2^{nd} generation with a PM motor is showing a significant gain versus the DUO/tandem configuration of about 20% annual saving and 28% against IC. This is due to the high efficiency of the compressor at low speed coming from the motor and internal design optimization.

Influence of the variation of the condenser thermal exchange

The purpose of this part is to evaluate the suitability of adding a condenser fan speed variation according to the climate.

	15 TON (Reference)		2 X 7.5 TON		DUO 7.5 TON		VSH117		15 TON intermittent		VSH117 2^{nd} generation PM	
	Mars	Nanc	Mars	Nanc	Mars	Nanc	Mars	Nanc	Mars	Nanc	Mars	Nanc
Annual consumption [kWh]	47277	41679	46232	41590	43904	39265	43908	39884	47042	42933	33558	30354
Annual energy savings [kWh]	0	0	-1045	-89	-3373	-2414	-3369	-1795	-235	1253	-13719	-12085
Annual gains [%]	0.0	0.0	2.2	-0.2	7.1	5.8	7.1	4.3	0.5	-3.0	29.0	28.5
Annual COP	4.62	5.10	4.72	5.11	4.97	5.41	4.97	5.33	4.64	4.95	6.51	7.00

Table 3: *Comparative results in Marseilles and Nancy (variable speed condenser ventilators)*

- The preceding conclusions are not modified and an annual COP improvement of 9% can be reached, with a maximum of 13% (COP 7 versus 6.2) being possible in the case of a variable speed compressor with permanent magnet motor. Adapting the speed of the fans allows for maximum benefit to be drawn from the best solutions of compressor capacity variation.

The following figure summarises the seasonal COPs obtained according to the climate:

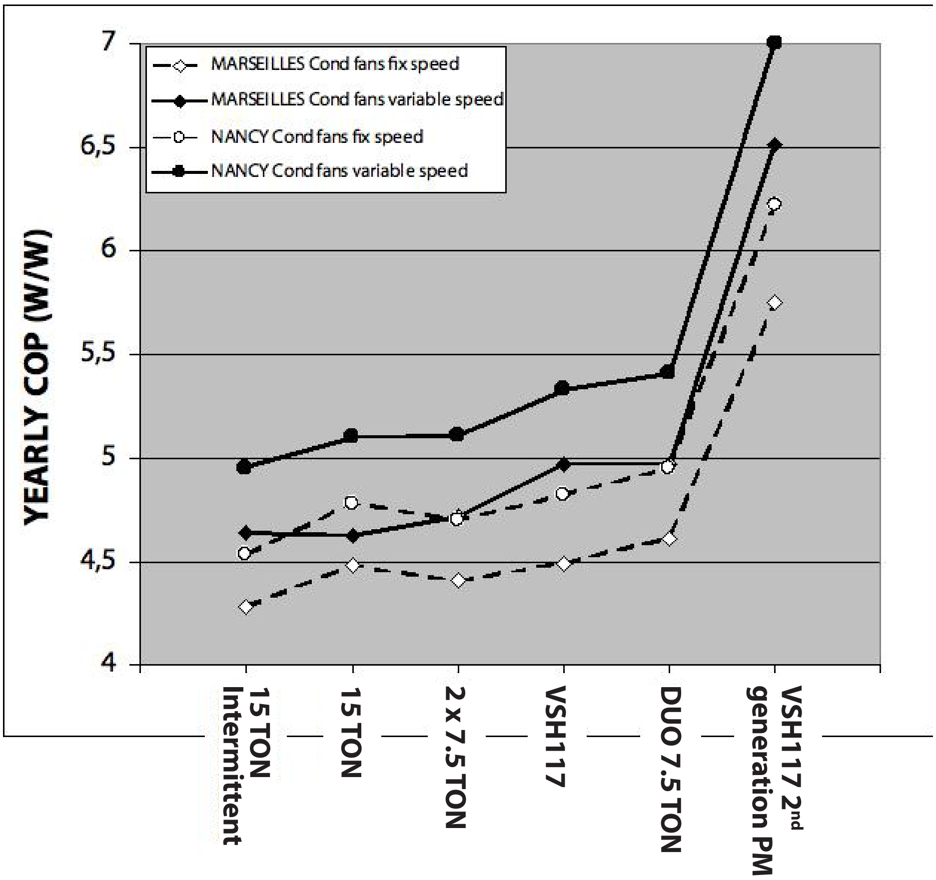

***Fig. 5:** Summary of the impact of the choice of compression technology and condenser exchange on the annual COP.*

To summarize, following observations can be made:

- Climate has a 10% impact in this example on seasonal performance, irrespective of the compressor technology chosen.
- The condenser fan frequency variation itself contributes an average seasonal gain of around 9%.
- Variable speed VSH 2nd Generation with PM motor is by far the best technical solutions to ensure a maximum seasonal performance.

Conclusions

In the future, thermodynamic systems must be designed to ensure that the production of heat or warmth is adapted to fluctuating requirements throughout the year.
The example of the chiller dealt with in this article clearly shows that the choice of compression technology is of capital importance and that its influence on the annual COP can reach 54% (COP 4.5 for IC compressor fix speed condenser fan versus 7 for variable speed compressor VSH2 with variable speed condenser fan).

The influence of climatic conditions has also been mentioned and shows that the best choice in terms of performance must consider the application, the compression technology and the local climate.

This approach applied to another application (heat pump, refrigeration installation, air/air system…) or oversized system would give different results and have completely different effects. Likewise, taking into account OFF period consumptions (crankcase heaters…) would significantly change this result in favour of the frequency variation versions, due to the short stopping time that they allow for.

Acknowledgements

The authors would like to thank Philippe RIVIERE from the Ecole des Mines de Paris for his invaluable assistance in the synthesis and analysis of the content of the measuring standards.

The Danfoss product range for the refrigeration and air conditioning industry

Danfoss Refrigeration & Air Conditioning is a worldwide manufacturer with a leading position in industrial, commercial and supermarket refrigeration as well as air conditioning and climate solutions.

We focus on our core business of making quality products, components and systems that enhance performance and reduce total life cycle costs – the key to major savings.

Controls for Commercial Refrigeration

Controls for Industrial Refrigeration

Electronic Controls & Sensors

Industrial Automation

Household Compressors

Commercial Compressors

Sub-Assemblies

Thermostats

Brazed plate heat exchanger

We are offering a single source for one of the widest ranges of innovative refrigeration and air conditioning components and systems in the world. And, we back technical solutions with business solution to help your company reduce costs, streamline processes and achieve your business goals.