A technical-economic comparison of two unit coolers operating with frost formation

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1. Introduction

This document sets out to illustrate the experimental results obtained from the comparison of a LU-VE unit cooler with a unit cooler from a COMPETITOR, in standard test conditions (without latent contribution) and in frost formation conditions.

Most unit coolers operate in cold rooms with frost formation, i.e. with high a level of humidity in the air. Tests carried out in these conditions enable us to understand the overall behaviour of the machine during its complete real function cycle. From this it is possible to determine the global cost of operation, including the costs concerning ventilation only, defrosting and finally the compressor unit.

In this experimental study we highlight once again the fact that the external surface (fins + collars) is not – for a great number of applications – a fundamental parameter in the choice of a unit cooler.

In detail we shall see that despite the fact that the LU-VE unit cooler has a 60% smaller surface area, it still manages to have operational costs that are 8% less.

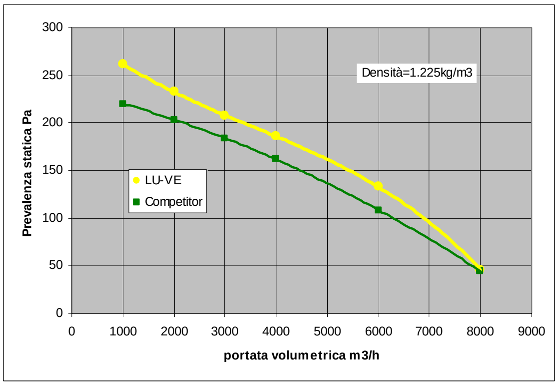
2. Tests of air quantity and refrigerating capacity in standard SC4 conditions (in the absence of latent contribution)

The experimental tests initially determined the air quantity and the characteristic curve of the fan (coupled to the heat exchanger coil) as well as the related electrical absorptions.

This information, apart from enabling a direct comparison with the data declared in the catalogue, also lets us understand how the air quantity will behave as a function of the frost quantity deposited on the external surfaces.

Clearly, the more "vertical" the curve remains (without any concavity inversion – "saddle point"), the better will be the behaviour of the during the frost test.

This characteristic of the fan group also depends on the optimization of the conformation of the outlet mouth and grille (LU-VE uses an outlet mouth with a high rim, reduced radial play, directional grilles etc).



Standard refrigerating tests were carried out in SC4 conditions, which is to say:
chamber temperature = -25°C
evaporation temperature = -31°C
superheating equal to 0.65 of DT1
liquid temperature upstream of the thermal expansion valve = 20°C.
In these conditions which are among the most severe for a unit cooler, the results in the following table were obtained.

Modello	Diam. ext	Tipo tubo	Passo	Sp. alette	Fluido	Portata aria		Delta		Potenza termica		Delta	Potenza Assorbita		Delta	Superficie		Delta
	mm		mm	mm	refrig. prova	m3/h	m3/h	%	SC	DT1=v.SC_	DT1=v.SC_	%	W	W	%	m^2	m^2	%
						TEST	CATALOGO	CAT/TEST	Test evap.	CATALOGO R404A dry	TEST R404A	CAT/TEST	TEST	CATALOGO	CAT/TEST	TEST	CATALOGO	CAT/TEST
F50HC 1806 E 7 - LUVE	13,15	RIGATO	7,50	0,30	R507A	15474	16200	4,7	4	11760	12510	-6,0	1340	1400	4,5	54,7	54,3	-0,7
COMPETITOR	13,45	RIGATO	7,00	0,15	R507A	15072	15100	0,2	4	11485	10130	13,4	1500	1540	2,7	87,2	94,4	8,3
DELTA COMPETITOR/LUVE			-7%	-50%		-3%	-7%			-2%	-19%		12%	10%		59%	74%	

The first part of the table shows the construction features of the heat exchanger coil; the second part shows the comparison of the experimental data for air quantity, refrigerating capacity, electrical absorption and external surfaces, all compared to the declared values in the catalogue.

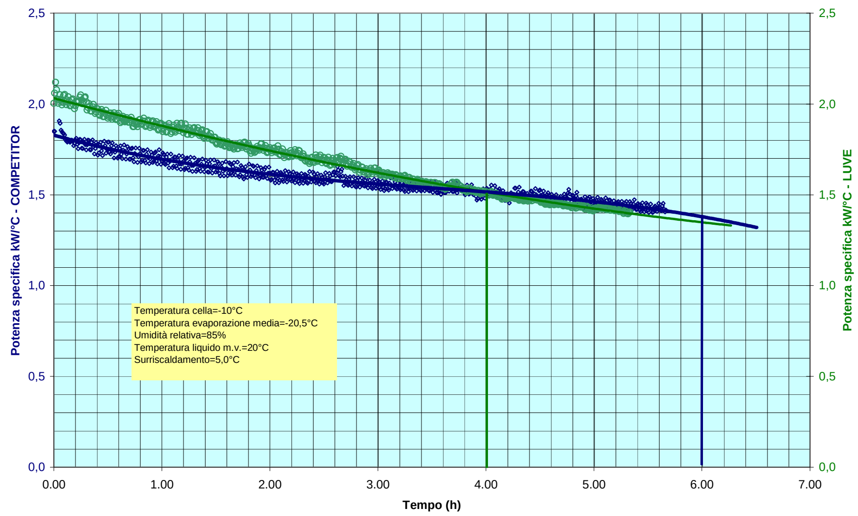
The air quantity and electrical absorption of the fan groups are within the EUROVENT tolerances, while the refrigerating capacity and the external surface of the COMPETITOR unit cooler are outside the imposed limits.

In particular, it was noted that the COMPETITOR equipment has design deficiencies concerning function at low temperature which have a consequent negative effect on the refrigerating capacity; so much so that the divergence from the catalogue data is 13.4%.
Another point in LU-VE’s favour is the greater efficiency of the fan group (+15%); as such, it has a greater air quantity +2.5%), and lower electrical absorption (-11%).
Furthermore, the LU-VE equipment uses thicker fins (in this case double: 0.30 vs. 0.15 mm), in order to improve the robustness of the fins, the construction process technique and the efficiency (a very important parameter in wide geometries, such as those found in unit coolers.)
I would like to emphasise that the LU-VE unit cooler, with 60% less surface area than the COMPETITOR, gives the same refrigerating capacity (catalogue data). This is thanks to the specialized surfaces and better design logic. In reality the experimental data show that the refrigerating capacity of the COMPETITOR’s equipment is in fact 19% less.
Finally, if we take into consideration the ratio of refrigerating capacity to the power absorbed by the fans in the two configurations, we get the following surprising results:

- LU-VE: 12510/1340=9.34 (+38%)
- COMPETITOR: 10130/1500=6.75.

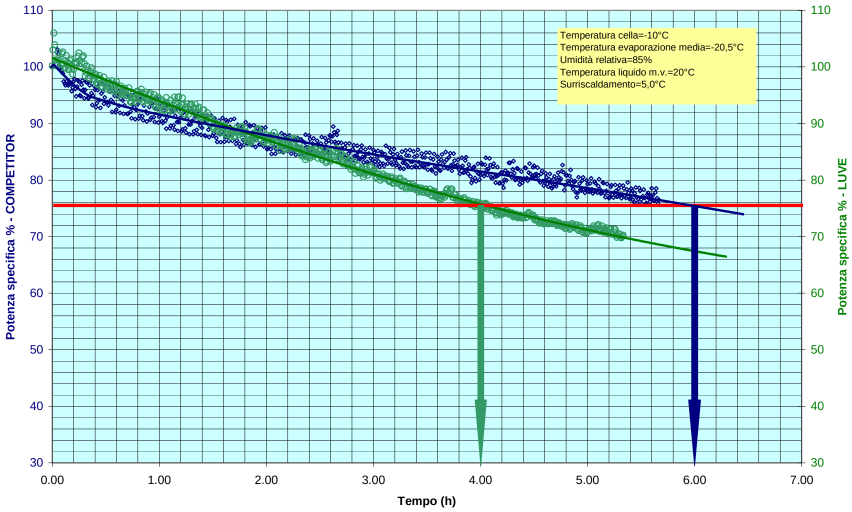
3. Frost test (with sensible and latent contribution)

The tests with frost formation on the fin surface were conducted in the following operational circumstances:
chamber temperature = -10°C,
relative humidity = 85%
average evaporation temperature = -20.5°C
superheating = 5.0°C
liquid temperature upstream of the thermal expansion valve = 20°C.
The test used the following methodology: at the start there were stationary conditions with low values of relative humidity, after which steam was introduced into the calorimetric room reaching a value of 85%. At this point, maintaining temperature and relative humidity constant in the chamber, the refrigerating capacity and relative temperature of evaporation registered a continuous fall.
When the refrigerating capacity fell by 25% of its original value, the plant was stopped and the electrical defrost was activated; once this finished, the basic operational cycle of the unit cooler was considered to have been concluded.
Here below is the experimentally obtained graph of the specific refrigerating capacity as a function of time (green for the LU-VE unit cooler and blue for the COMPETITOR’s unit cooler).
Specific capacity is defined as the ratio between the refrigerating capacity and the DT1 (in conditions without frost formation, such a ratio remains constant over time).



In the conditions indicated above, the difference in refrigerating capacity is about 14% (to LU-VE’s advantage). This gap, during continuous operation, is annulled after about 4 hours. This is the point at which the LU-VE unit has reached a decrease of 25% of performance and consequently requires the intervention of the electric defrost system.
The COMPETITOR’S unit took 6 hours to reach this limit.
In practice, these operational time limits have to be increased by a utilization factor (ratio: compressor running hours/daily total hours), i.e. a coefficient which takes into consideration the fact that the unit coolers do not function in continuation but are dimensioned with a certain safety margin, as a consequence the refrigeration pack switches off when the set temperature of the room has been reached.
In order to equalize the net/useful refrigerating energy exported from the cold chamber (e.g. on a daily basis) by the two machines being analyzed, it is necessary to consider a use factor of 0.87 for the COMPETITOR (normal used value) and 0.63 for LU-VE as it expresses a greater average refrigerating capacity (i.e. Fu=0.67: 24x0.67=16 h compressor On, 8 h compressor Off).
As a consequence, the “real operational time per cycle” is 4/0.63=6.35 hours for LU-VE and 6/0.67=8.96 hours for COMPETITOR

The graph below shows in percentage terms the decrease in refrigerating capacity as a function of time. This enables us to define the operating time limit of the unit cooler, presetting a performance-decrease value compared to the original data (e.g. -25%: the value over which the thermostatic valve begins to render the refrigerating plant unstable). In this way the above mentioned times are obtained: 4 hours for LU-VE and 6 hours for COMPETITOR.



At this point, having extracted all the information about the behaviour of the two unit coolers during frost formation (refrigerating capacity, electrical absorption of the fans, defrosting time and consumption parameters), we can proceed to an economic and energy comparison.

4. Conclusions (a comparison of economy and energy use)

The elaboration of the experimentally obtained information is summarized in the table below.
The following values are indicated: the refrigerating capacity at the beginning and end of the frost cycle; the fin space; the external surface area; the specific initial thermal flow referring to the external surface; the power absorbed by the electric heaters during defrost; the previously-defined use factor (i.e. the multiplication factor of the total hours – e.g. 24 hours per day) to obtain the real operating time of the unit cooler); frosting time; defrosting time; the number of daily cycles; the thickness of frost deposited on the fins and collars (average value); the average COP of the cycle; the useful refrigerating energy/daily net (maintained constant in both unit coolers modifying the use factor) and finally the running costs (totals and percentage relating to compressor, fan and defrosting components).

	Dati sperimentali																
Tipo aero-evaporatore	Potenza specifica		Passo	Sup ext	Dry flux	Pass Ve	Pass Res	Futilizzo	Tempo	Tempo	n° cicli	Spessore	COP	En. Frigo utile	Costo esercizio			
	iniziale	finale							brinatura	sbrinamento	giorno	brina	medio		tot	comprex	ventil	resist
	W/°C		mm	m2	W/m2/°C	W	W		min	min		mm		kWh/giorno	€/anno	%	%	%
COMPETITOR	1800	1380	7,0	87,8	21	1500	11200	0,63	360	30	2,54	1,1	1,85	**204**	10665	70	23	7
LUVE F50HC 1806E7	2100	1510	7,5	55,1	38	1340	7840	0,67	240	27	3,52	1,2	1,87	**204**	9829	72	21	7

Condizioni di prova : Tcella=-10°C, Tevaporazione media=-20,5°C, UR=85%, Tlmv=20°C, Dtsurr.=5°C

As explained before, given that the LU-VE unit cooler has expressed greater refrigerating capacity, in order to make a correct comparison at equal useful refrigerating capacity (204 kWh/day), the use factor was reduced from 0.67 to 0.63. In this way, a reduction of 6% in refrigerating cycle operating hours was taken into consideration.
Concerning the electric defrost, it can be seen that the value of the electrical power relative to the defrosting heater applied to the LU-VE unit cooler is 30% less than the COMPETITOR (less fin surface to defrost) while the defrost time remains roughly the same (about 30 minutes). Consequently, even if the LU-VE unit cooler has to carry out 39% more defrosting (3.52/2.54), the energy consumed in nevertheless 13% less, that is:
energy consumed per defrost, LU-VE = 7.84x(27/60)x3.52= 12.4 kWh/day
energy consumed per defrost, COMPETITOR = 11.2x(30/60)x2.54= 14.2 kWh/day (+14.5%).
However it must always be remembered that that the energy savings on the electric defrost have to weighed against a percentage of 7% of the total running costs (a value 10 times inferior compared to the contribution of the compressor).
In terms of electrical energy consumption for the fans, we have the following situation:
ventilation input energy, LU-VE = 1.34x4x3.52= 18.9 kWh/day
ventilation input energy, COMPETITOR = 1.50x6x2.54= 22.9 kWh/day (+21.2%).

The total running cost, based on the cost of energy in Italy, in the above-mentioned hypothesis (electrical energy cost: 0.14 €/kWh) amount to **10665 €/year** for the COMPETITOR unit cooler and **9829 €/year** for the LU-VE unit cooler.
To summarize, the operating costs of the COMPETITOR unit cooler are **8.5%** more than the LU-VE unit cooler, 4.2% resulting from the greater electrical absorption of the fans, 0.8% from the defrost system and 3.5% from the compressor.
The financial saving is **836 €/year** (10665-9829). This amount allows the user to re-purchase a NEW machine from LU-VE after only **26 months** of operation (against a minimum life of the unit cooler of 10 years).

Hypothetically, spending an initial 20% extra to purchase the LU-VE product (equivalent to 300€) would mean using 300€ with an annual compound yield of **40% for 10 years.**

The table below shows the PBT (pay-back time) calculation for the LU-VE unit cooler compared to the COMPETITOR; hypothesizing a discount of 50% of the list price, a recovery time of **4.3 months** is obtained!

Tipo aero-evaporatore	Listino		Delta	Delta	P.B.T
		Sconto	prezzo	Ce	
		50%	€	€/anno	mesi
COMPETITOR	2990	1495			
LUVE F50HC 1806E7	3590	1795	300	-836	4,3

Analyzing the operating costs and hypothesizing that both machines have the same initial refrigerating capacity (and NOT 14% difference), better results are in any case obtained using then LU-VE unit cooler i.e. the new total running costs are 10152 €/year, compared to 10665 €/year for the COMPETITOR unit cooler (**+5.0%**).

Apart from all the technical and economic advantages amply illustrated here, it is worth repeating yet again that the greater external surface area of the COMPETITOR unit cooler causes – at equal useful/net refrigerating capacity – a significant disadvantage to the running costs.

Other plus points of the LU-VE unit cooler vs. the COMPETITOR unit:

- Pre-installed drain tray (not supplied separately to be fitted as with COMPETITOR)
- Better finishing of the casing surfaces
- Lower electrical plant costs (lines, accessories etc9 for defrosting and fans
- Better electrical wiring
- Coaxial drain tray and counter-drain tray outlet (COMPETITOR: central counter-drain tray outlet and rear drain tray outlet. (Longer water travel route between the two outlets: danger of ice in the drain tray!!).

5. Nomenclature

TS' = evaporator inlet air temperature
UR = percentage relative humidity
Te = evaporation temperature at the outlet of the unit cooler
DT1 = TS'-Te
P.B.T. = investment recovery time (not updated)
COP = Coefficient of performance of the refrigerating cycle
Sup. Ext. = fin surfaces + collars ("touched" by the air flow)
Dry flux = specific heat flow (sensible energy / external surface / DT1)

6. Bibliography

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