

ENERGY EFFICIENCY MAXIMIZATION OF A VERTICAL DISPLAY FREEZER

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In order to satisfy the requirements of European regulations, the design of professional plug and play refrigerating appliances in the last years is oriented to use R290 refrigerant, an hydrocarbon with GWP equal to 3. The need of a better environmental sustainability of refrigerating appliances is a topic which is increasingly felt by final users and offers important opportunities to reduce both equivalent CO₂ and environmental impact during the lifecycle, with tangible saving in the cost of electrical supply.

In this work a Marilyn 450 BTQ vertical freezer display, operating with R404A, has been analysed. It is engineered for the purposes of exhibiting, selling and operator-assisted servicing of ice cream products. There have been two objectives:

1. Reengineer the cooling circuit of the display freezer for R290, pursuing the maximum energetic efficiency possible, using state-of-the-art technology and particularly a hermetic variable speed reciprocating compressor with an inverter.
2. Acquire know-how, components and a thermodynamic solutions which are scalable and usable, with appropriate simplifications, in other fixed speed compressor projects.

The product – Tecfrigo Marilyn 450 BTQ inverter



Kind of appliance and functionalities	Vertical freeze cabinet for display, sale and assisted-service catering of not prepackaged ice cream products
Volume	450 L
Temperature	-5 / -21 °C
Supply	230 V, 1, 50 Hz
Refrigerant and charge	R290, 85 g
Cooling mode	Forced ventilation
Defrost	Hot gas
Standard equipment	5 glass shelves
Energy labeling	Not applicable

The R290 reengineered vertical freezer display maintains all the construction features of the previous R404A appliance: in particular, no variations have been applied to components which determine the heat exchange between environment and refrigerated compartment (glazing, insulations), because already optimized on R404A display. Specifically, the appliance is a 450 litres ventilated freezer, equipped with 5 glass shelves as standard, operating at a temperature settable between -5 and -21 °C. The four sides are made with double glazing, filled with argon gas and treated with magnetron process to ensure low emissivity. The electrical supply is single phase 230 V – 50 Hz and the defrost is hot gas architecture. Due to the numerous functions and

the intended use modality, the showcase is excluded from the current regulations for energy labelling.

Therefore, reengineering has been addressed on the components of the refrigeration circuit, in particular on the compressor, which is the component with the higher electric consumption. The initial R404A display freezer is equipped with a fixed-speed, oversized compressor to ensure performance and reliability even in extreme conditions. In order to achieve maximum efficiency on the new freezer, an Embraco VNEU213U variable speed inverter compressor has been selected, thanks to its performance characteristics (efficiency, low noise and vibrations, possibility of drop-in, frequency and serial control), choosing a serial interface for the communication with a parametric controller, featuring Wi-Fi and cloud connectivity. An R290 compressor, with identical displacement but fixed speed, was also identified, to set up a third vertical display, useful for a comparison with both the initial R404A appliance and the variable speed R290 compressor.



On both fixed speed compressor display freezers the gas expansion is obtained by a capillary tube, while for the inverter version an electronic valve with stepper motor and dedicated PID control driver has been chosen, allowing continuous mass flow regulation and maintaining of the correct overheating degree. In order to minimize the R290 refrigerant charge and the air side pressure losses, high efficiency grooved tube heat exchangers were used, reducing as much as possible the outside diameters of the pipes and the number of ranks, while maintaining a 30% oversizing. In particular, the 5 rows condenser with 12 mm tubes used for the R404A, has been replaced by a finned battery with the same frontal area, but with 2 rows of 5 mm striped tubes. Finally, the shaded-pole motor fans of the R404A showcase have been replaced by brushless permanent magnet motors: for the on-off R290 display freezer they are fixed speed, while for the inverter R290 display freezer they are variable speed with a range of 600-1400 rpm, in order to optimize heat exchange in different operating conditions.

The three display freezers have been tested in a condition 4 climatic chamber (30 °C, RH 55%): data of the instantaneous absorbed power by the grid and the temperatures on the upper, intermediate and lower shelves have been recorded through power meter and thermocouples, in the steady state, start-up and defrost conditions. Lacking a specific standard, the principles of EN 23953-2 have been followed, albeit with some deviations, aimed at better adhere the intended use: the test packs have not been placed as the appliances are typically used to display a few cakes; therefore, the food enthalpy can be supposed negligible. Furthermore, considering that the service is assisted, an opening of the door every hour has been considered.

The possibility of varying the compressor rotation speed between 1800 and 4500 rpm makes it possible to combine both the benefits of oversizing and under sizing of a fixed speed compressor, achieving high power, quick response and low consumption. From collected data analysis, it appears that, in regime conditions and in the chosen sizing, the variable speed compressor can operate continuously at around 2600 rpm: this, in combination with a PI or PID control, allows the constant pursuing of the set point temperature. Consequently, at climate condition 4, there is no longer an off-cycle, with resulting temperature hysteresis in the refrigerated compartment, which is usually equal to 3-4 ° C for on-off appliances: the temperature is maintained at about ± 0.15 °C of the set point, with benefit for food preservation.

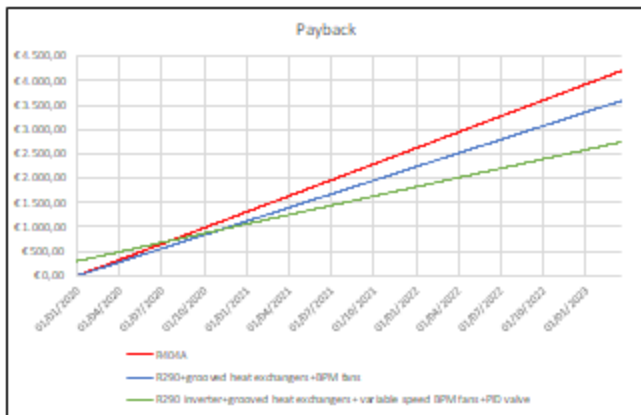
During the start-up transient, it is possible to reduce the pull down time, increasing the rotation speed of the compressor up to 4500 rpm, thus increasing the mass flow rate of refrigerant and hence the cooling capacity.

The tests on the vertical freezer display showed a 36% time reduction for a pull down from 20 to -18 ° C compared to the R290 display with on-off compressor: it decreases from 124 to 80 minutes. Furthermore, the energy consumption for this phase is reduced by 29%, from 970 to 690 Wh. The pull down has a strong impact on the temperature recovery after door openings, so its control permits to considerably reduce the daily consumption of the application.

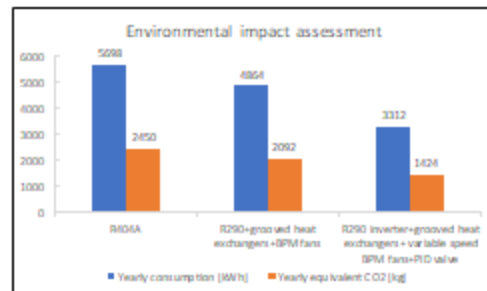
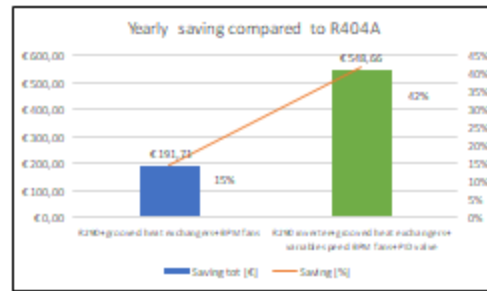
Basing on respective consumption and mean energy cost, an economic framework for the three in-service cases has been calculated. The R290 showcase with fixed speed compressor showed a 15% consumption reduction and the R290 display with variable speed compressor a 42%, both compared to the initial R404A display.

Considering that these reductions mean respectively savings of 192 €/year and 549 €/year against the R404A application, in both cases the freezer with variable speed compressor has the payback of the differential cost (due to additional components) within one year. From the environmental point of view, the equivalent CO₂ reduction for the used electricity is remarkable: CO₂ decreases from 2450 for R404A to 2092 for R290 to 1424 kg/year for the most efficient vertical display with inverter compressor.

Power consumption



Cost of energy is assumed to be 0,23 €/kWh



A 33% time reduction at 3000 rpm of the recovery phase after defrost is another important advantage emerged from the tests between the R290 inverter display and the equivalent R290 fixed speed compressor one.

In addition, for the inverter appliance, which is equipped with a variable speed evaporator fan, the refrigerated compartment temperature is maintained 1.5 °C lower on average, with advantages for food preservation. Similarly to the door opening phase, it is possible to setup the compressor pull down speed after defrosting, speeding up the reaching of the set point even more.

The vertical freezer with the variable speed compressor is about 5 dB less noisy than equivalent on-off appliance. Low noise is highly appreciated in vertical displays, which are often use in quiet environments, like restaurants, tea rooms, lounges. Moreover, the inverter compressor has a role on food preservation since relative humidity is maintained stable, helping not to dry ice cream products.

The choice of the serial interface allows the development of a proprietary and bidirectional operating logic, as the compressor with inverter is enabled to send feedback to the controller like data and warnings. These data are used both to create customer interfaces and to assist service technicians: many common anomalies are reported, such as incorrect refrigerant charge, excessive compressor temperature, lacking communication between inverter and controller. In the vertical freezer a connection to the cloud was installed via Wi-Fi, which allows data and alarms to be read, thus enabling post-sales remote assistance, time saving in diagnosis and avoiding lost service travels.