THE GREEN GAS RESEARCH PROJECT: LOW GWP REFRIGERANTS IN COMMERCIAL REFRIGERATION

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Introduction

The policy aimed at raising the awareness of environmental protection has forced the industrial refrigeration sector to operate in a permanent transition phase, which implies the gradual substitution of the working fluids used in refrigeration cycles. The transition from fluorinated fluids to new refrigerants has been neither trouble-free, nor affected by drawbacks; this has forced the refrigeration experts to tackle various problems, as for example the performance reduction of the equipment. This situation requires from the manufacturers great flexibility and spirit of adaptation as, according to the characteristics of the new refrigerants, the redesign of components or the adoption of different lubricants becomes necessary in some cases. The project Green Gas originates from the common need of three companies of the Casale Monferrato district, which operate in three different sectors of refrigeration: SandenVendo (beverage dispensers), Cold Car (refrigerated transport), and Heegen (display cabinets).

Progress in Green Gas project

In the first phase of the project, now completed, each company has identified the most suitable refrigerant for their relevant product category. Applications have then been developed, which took into account the specific exigencies of the manufacturer and the safety issues connected with the properties of the low GWP fluids, evaluating solutions readily accessible in the market.
For SandenVendo Europe the selected fluid was R290, a highly flammable hydrocarbon. This solution requires particular attention, as within an automatic dispenser several electric components are present, which may create electrical arcs in their functioning. Therefore, the option of using R290 in existing equipment has been ruled out from the very beginning, giving up the option of a simple retrofit. This option has been excluded, given the high flammability of the fluid and the difficulty of acquiring at acceptable costs components suitable to operate in potentially flammable environments.

Consequently, a feasibility study was carried out for a new refrigeration system that does not allow any gas leakage to propagate in enclosed areas located within the vending machine, thus avoiding the hazard of explosions. A dual refrigeration system was selected, composed of two circuits connected by an intermediate heat exchanger, which is responsible to transfer the cold generated by the primary circuit to the heat transfer fluid circulating in the secondary circuit, keeping constant the temperature of the goods inside the vending machine. Figure 1 shows the installed system solution, which has allowed to place the propane primary circuit in a safe and ventilated zone of the vending machine.

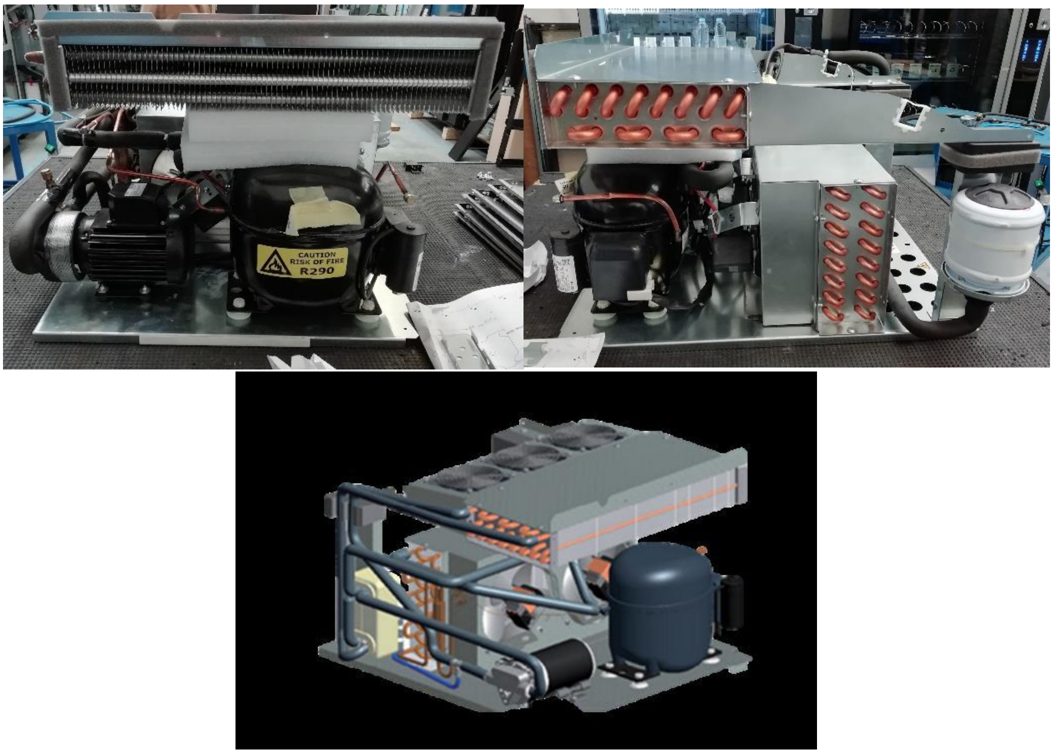


Figure 1: SandenVendo vending machine refrigeration system.

The design of the R290 primary circuit was based on the already known components used in R404A systems. Most significant changes concerned the internal diameter of the tubes and the type of evaporator. It was decided to employ tubes with a lower diameter to reduce the refrigerant charge, in order to respect the limits imposed by regulations. Regarding the evaporator, contrary to the traditional finned packaged coils, the choice fell on a plate heat exchanger, which was then appropriately coupled with the second glycol circuit. The design of the second circuit has been focused on the selection of the best suited glycol at low temperatures and on the type of pump for fluid movement within of the circuit.

The prototype was tested in climate chamber at 32.5°C-65% R.H (Figure 2) according to a reference standard that complies with the conditions required by the final customer for product validation. The tests have been performed on the G-Drink model with R404A refrigeration system and on the R290 new prototype. Figures 3 and 4 show the 24 hours fully-loaded pull-down test (504 cans), in which the design conditions (average internal temperature 2°C) were reached respectively after 16:27 h and after 16:16 h. Contrary to what it could be expected, the installation of the second circuit has not affected negatively the daily energy consumption; indeed, as it can clearly be seen in the graphs below (figures 5-6), there is even an enhancement of system performance. In fact, with the same conditions and thermal loads, the R404A system recorded 8.51 kWh over 24h energy consumption, and 8.41 kWh for R290.

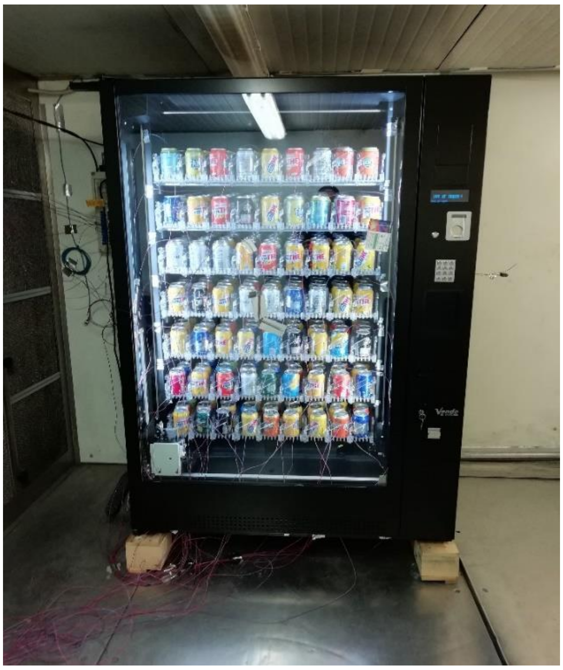
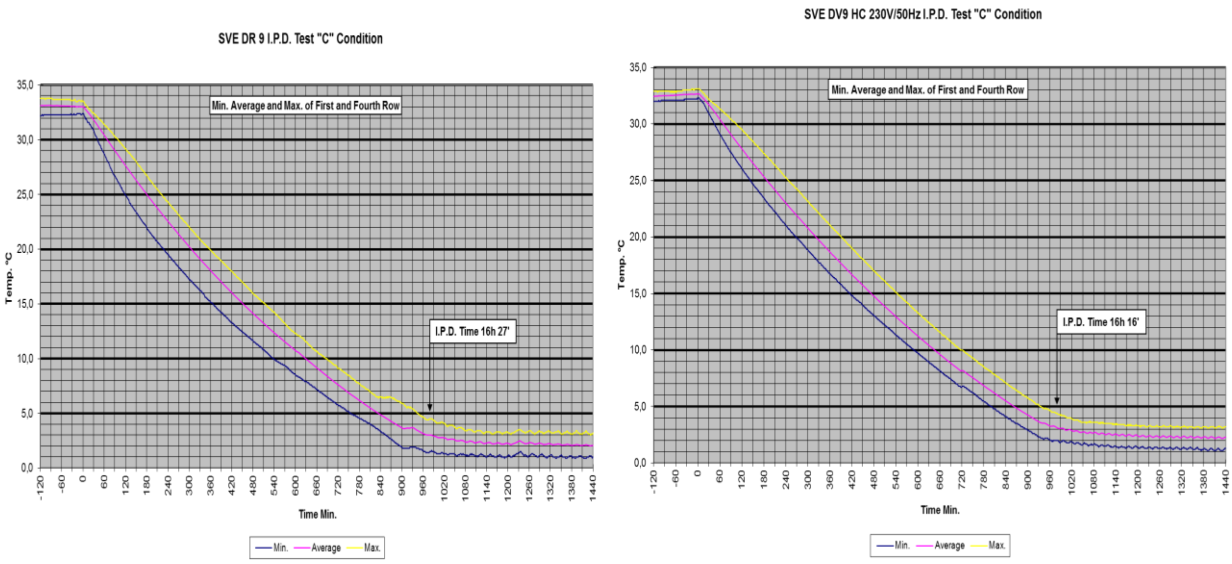
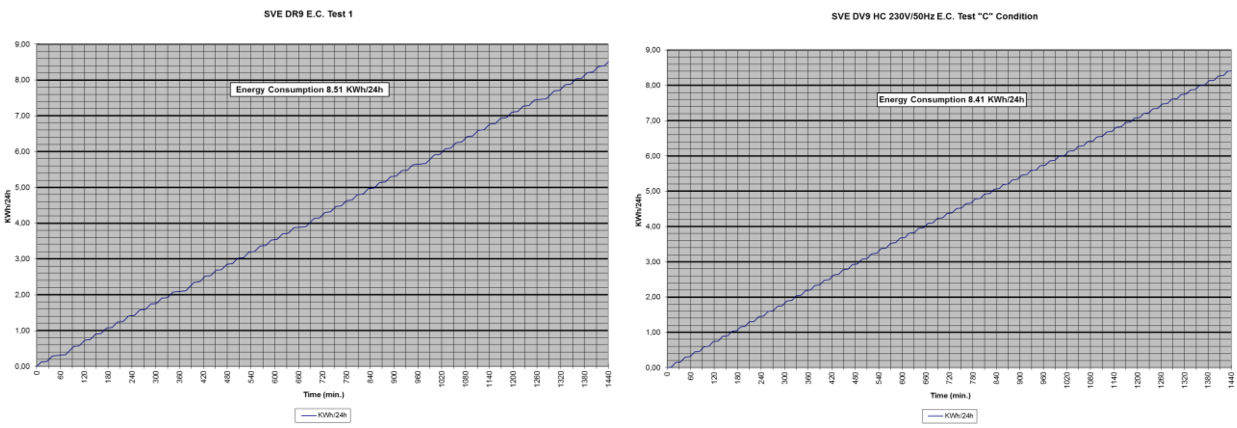


Figure 2: Vending machine in climatic chamber.



Figures 3-4: Pull-down test performed on R404A system (left) and R290 (right).



Figures 5-6: *Daily energy consumption on R404A system (left) and R290 (right).*

Regarding the Cold Car partner, working in a refrigeration field subject to fewer regulation restrictions and using remote systems with high refrigerant charge, has allowed to select HFO-HFC mixtures for the refrigerant gas, and at the end R452A has been indicated as the most suitable solution for this application (See figure 7).

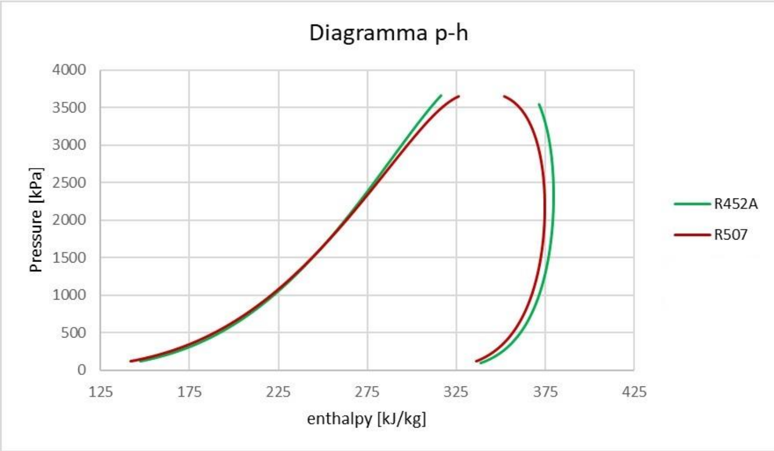


Figure 7: Diagram p-h R452A and R507.

It was verified that the existing systems operate correctly with the new refrigerant mixtures applying only a retrofit operation; after this verification, the activities have focused on the evaluation of system performance through testing, in a climatic chamber, a reference body truck (Figure 8) with the following characteristics:

- Dimensions: 3600 x 2040 x 1550h (external), 3400 x 1840 x 1250h (internal)
- Panels with increased thicknesses: roof and floor 150 mm, vertical panels 100 mm
- N°8 side doors 550x900h (clear light)
- Refrigerant unit with compressor Frascold D3-18.Y(CC). Feeding condensing unit by electricity grid (380-400V, 50Hz)
- Condenser X89 6 rows / 16 tubes – exchange surface 11.5 m^2
- n° 1 elicoidal electric fan with 7 blades ∅ 350 mm – air flow 3100 m^3/h measured at free discharge condition
- Global heat transfer coefficient of 0.22 $W/m^2/°C$

Figure 8: Reference body truck used in climatic chamber.

Comparative tests were carried out in a temperature-controlled room on two refrigerated bodies identical in size, insulation and cooling equipment, but with two different refrigerant fluids: the traditional R507 currently in use, which will be banned and replaced by environmental friendly fluids, such as R452A and R448A, that have similar thermodynamic properties. The temperature inside the climatic chamber is kept at the desired values by heating devices, thus allowing the body to be preserved in uniform environmental conditions for the whole duration of the test. A series of probes detect the temperature data that is transmitted to a recorder at pre-set time intervals.

The refrigeration system used in the body is a simple vapor compression cycle consisting of an air-cooled condenser, a compressor cooled by air exiting the electric fan applied to the condenser, two thermostatic expansion valves and an evaporator. The evaporator is coupled with five plates containing an eutectic solution for the accumulation of cold, with liquid-solid phase change at a temperature of -33 ° C. The condensing unit is installed outside the body, under the floor on the right side, and works only during the vehicle stop at the end of service, with power supply (380-400 V and 50 Hz). The main components of the condensing unit are the semi-hermetic motor compressor and the condenser. The circuit is also equipped with devices calibrated to control the high and low pressure. The internal temperature is checked by a thermostat set to a value that guarantees the conditions of use. In this case, -42 °C with 5 °C differential and with NTC probe in contact with the last eutectic plate of a circuit. Furthermore, an energy meter, which measured the absorbed energy by the refrigerating unit, was placed at the terminals of the condensing unit to pull-down the temperature of the cell to the design conditions.

The first test was carried out in accordance with the procedures defined in the ATP standard: insulated test chamber with a constant ambient temperature of 30 °C and a heat gain of 120 W placed inside the body during the evolution phase which follows the period of charge of the eutectic system. From the temperatures detected, there is a very similar trend in the values found both in the first 24 hours of the charging phase and in the following 12 hours with the refrigeration system off. The internal temperature, resulting from the average temperature of the probes positioned inside the cell, has a similar trend for both R507 and R452A as shown in the chart below (Figure 9).

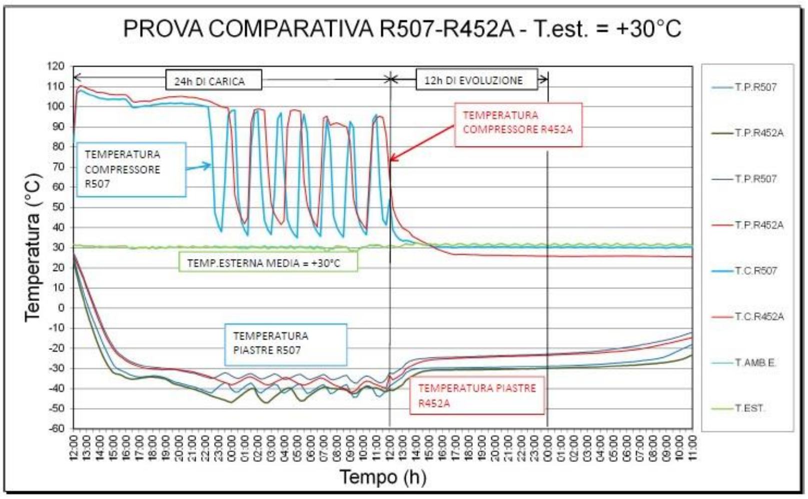
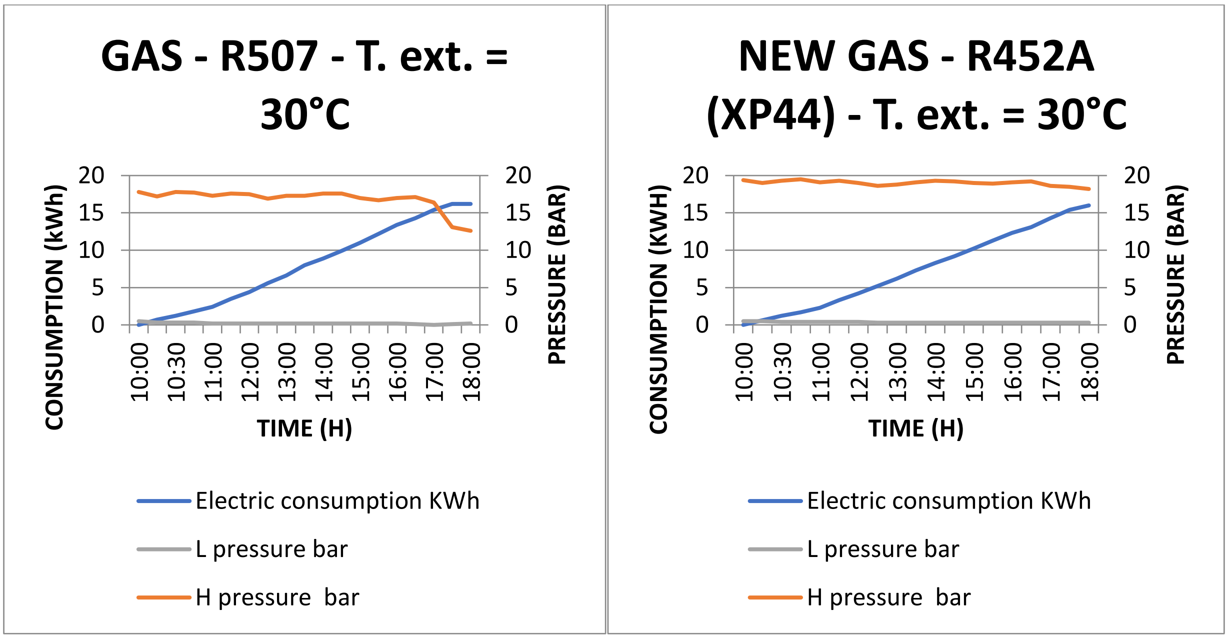


Figure 9: Temperature trends comparative test (30°C ambient temperature).

It can be notices that, for the probes placed on the eutectic plates, the temperatures achieved with R452A are slightly lower than those obtained with the standard R507 system. This trend is particularly evident in the ON-OFF phase of the thermostat with a higher absorption by the compressor, therefore implying a higher energy consumption. The 24h energy consumption data indicate a 40.2 kWh value for the R507 system, compared to 41.1 kWh for the R452A solution. This represents a 2.24% energy consumption increase for the new solution with respect to the standard system. The manufacturers had estimated a reduction in compressor output of about 8%, but differently to this prevision, the performance of the new gas was overall quite satisfactory. In the graphs below (Figure 10-11) it is shown the recharging phase after service, up to the stop determined by the thermostat, in this case too, the low and high pressure values, in the evaporation and condensation phases respectively, can be noticed. The higher compression ratio of the new fluid with respect to the traditional one is visible, which may justify the detected increase in energy consumption.



Figures 10-11: Comparative performance test at standard condition (30°C ambient temperature).

After the comparative test at standard condition, a performance comparison in extreme conditions (40°C ambient temperature) was carried out, without modifying any of the system components. As expected, the work expended by the compressor to bring the plates to the final temperature is higher, which implies more power employed for a longer time. As it can be seen from the graph below, the charging period up to thermostat stop becomes 15 h for R507 (in the previous test, it was 10:30h) and 15:45h for R452A (previously it was 12h).

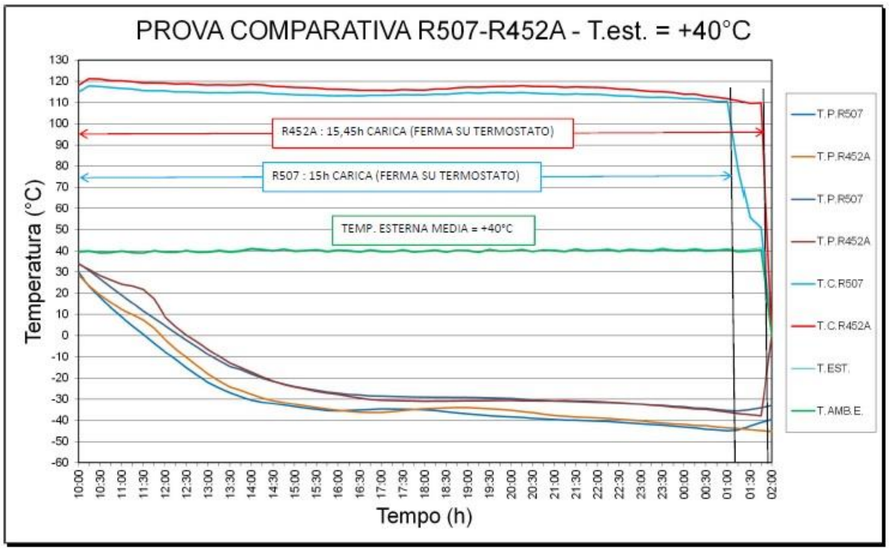


Figure 12: Temperature trends in the comparative test (40°C ambient temperature).

Figure 12 shows similar trends of the temperature probes placed on the plates and an increase of the compressor temperatures. This behavior is predictable, considering the most severe environmental condition, but that confirms the interchangeability of the two compared fluids, without changes in the system components and layout.

Finally, the energy consumption data measured in the 30°C ambient temperature test are considered. It has been observed that the 24h total energy consumption is lower in the cell with the new gas, compared with the one detected in the 30°C test (Figure 13). In these conditions, the 24h energy consumption was 49.8 kWh for R452A, while for R507 it was 51 kWh.

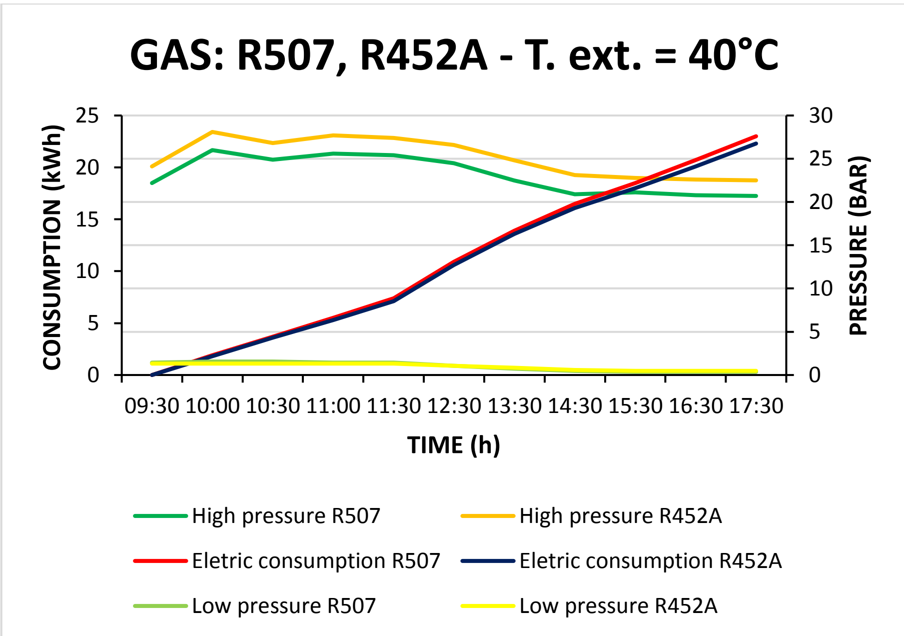


Figure 13: Energy consumption in the comparative test (40°C ambient temperature).

The 1.2 kWh energy saving, corresponding to 2.35% of the total R507 total consumption, may be considered as a promising result, considering that Cold Car units are in use in countries with environmental conditions similar to the 40°C test. The reduction in primary energy consumption implies a significant positive effect on the environment, particularly on a life-cycle basis, since the energy consumption is the prevalent impact of the product. The better performance with R452A arises from the lower compression ratio detected during the entire 24h cycle.

Heegen, while had initially considered to use R290 as replacement fluid, has decided to adopt in the short term R452A in their plants in order to cope with the demand of some customers, particularly foreigner, which had expressly required the plant of the display cabinet to be charged with non-flammable fluids. This choice will allow Heegen to provide a product compliant with the in force regulations without modifying the system components, while planning the necessary actions to adopt R290 in their entire product range. The next step will be the production of a first prototype of a display cabinet operating with R290, for which the necessary performance and safety tests will be carried out.