

Energy efficiency strategies in refrigeration systems of large supermarkets

J.M. Garcia, L.M.R. Coelho

Abstract—Energy efficiency and its relationship with sustainable development are one of the most important objectives in modern engineering systems. In Industrial Installations that use refrigeration systems that are associated with the food industry, this optimization of energy consumption associated with the achievement of high quality standard is one of the main objectives of the modern engineer. One of the most important sectors in the distribution industry is the large supermarkets. In this kind of plants the annual amount of costs associated with all the refrigeration equipments that exists inside (cold chambers, preparing rooms, displaying cabinets) achieve values that in some cases represent more than 50% of the total energy consumption costs. With this background all strategies that conduce to reductions in refrigeration energy consumption should be considered. This article is about this kind of strategies that can be made in the refrigeration systems and equipments of a large hypermarket to reduce refrigeration energy consumption. Special attention is given to the variation of evaporation and condensation pressure, utilization of scroll compressors, utilization of efficient control systems and equipment.

Keywords— Energy efficiency, refrigeration systems, Supermarkets, optimizing parameters

I. INTRODUCTION

With recent developments in the energy field, the impact of energy consumption and its relationship with sustainable development is one aspect of primordial importance in engineering systems. The concept of sustainable communities with its three components (economy, society and environment) is directly connected with the rational utilization of energy, both at a local level, and at a global level. These three aspects of sustainability are in most case difficult to evaluate and the aspect of energy consumption should be carefully considered.

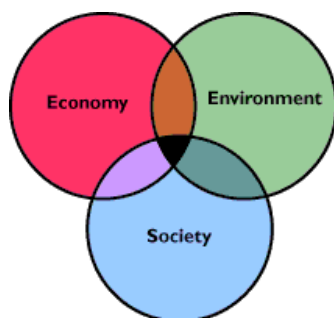


Figure 1 – The economic, environment and society aspects of sustainable development [1]

With the recent increase in the number of large supermarkets (Hypermarkets), this sector of activity had increased its importance and weight in energy consumption related to other economic activities. A study made in Portugal by INETI [2] concludes that in this kind of superficies there are no energy consumptions below 500 Tep/year, and in most cases the energy consumption is above 1500 Tep/year. These results had been achieved after a fieldwork based in inquiries and energetic judgements.

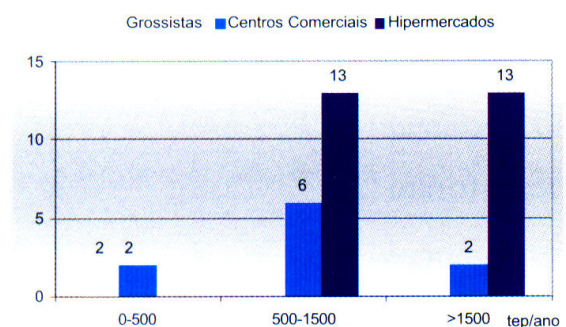


Figure 2 – Global energy consumption [2]

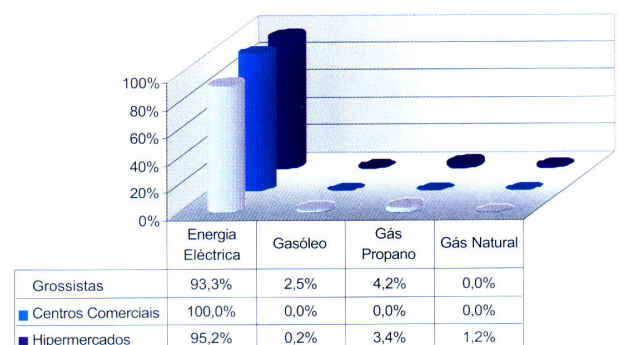


Figure 3 – Energy consumption in commercial spaces [2]

The same study [2] concludes that electrical energy is the main kind of energy used (95,2%) followed by far by the second type of energy (1,2%) natural gas.

One of the most important energy consumption sectors in a hypermarket is the energy used related with the refrigeration activity. This cost represents a mean value about 30% of the final energy used in this activity [2]. So the scope of this

article is to discuss the possibility of energy savings related to the refrigeration systems and equipment in supermarkets and hypermarkets. Nevertheless, many of the aspects discussed in this article, can be extended and applied to refrigeration systems of other refrigeration plants, industrial and commercial.

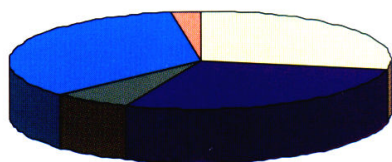


Figure 4 – Energy consumption by sector [2]

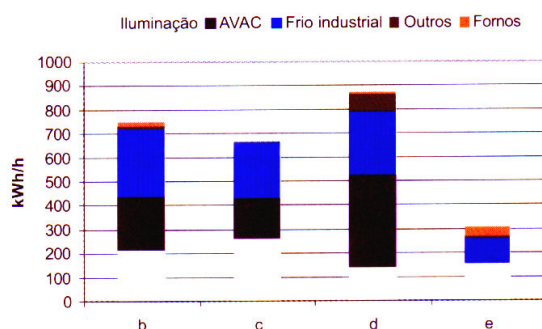


Figure 5 – Desegregation of consumptions by sector [2]

II. ENERGY SAVING STRATEGIES IN REFRIGERATION

With this scenario of high dependence of electric energy in great supermarkets, two strategies are primordial to achieve our goal of sustainability and environment respect in these installations. We remember that these articles focus only the refrigeration systems, and the other systems like HVAC, lights, hot sanitary water, bakeries, ovens, are out of the scope of this article. So, to achieve our goal, related with the refrigeration systems we can:

- i) Try to replace the electric consumption by alternative forms of energy especially renewable energies.
- ii) Try to reduce the global electric consumption in hypermarkets using more efficient systems.

The first line of action – trying to replace the electric consumption by alternative forms of energy - is today maybe the most difficult of both strategies. In fact nowadays, the great majority of the actual refrigeration systems use the vapour compression cycle with one stage or multistage compressors. This kind of systems uses electric energy to drive the compressors, essentially because of the substantial amount of power needed when compression is made. In fact Lindhart [3] sustain that in current supermarkets compressor are responsible for almost 50% of the total energy consumption

due to refrigeration. The only two alternatives that the refrigeration “state of art” knows are the absorption cycles and the adsorption cycles. But these cycles have some practical problems when the engineers try to implement them. The usage of other forms of energies like wind, solar, geothermal and seas have nowadays too many limitations to be considered as valid solutions. In fact the costs associated to this systems associated with the inexistence of tested equipment that can be used using this forms of energy, jointly with the specific difficulties associated with this systems when implemented in real installations, are sufficient to discourage the refrigeration engineer.

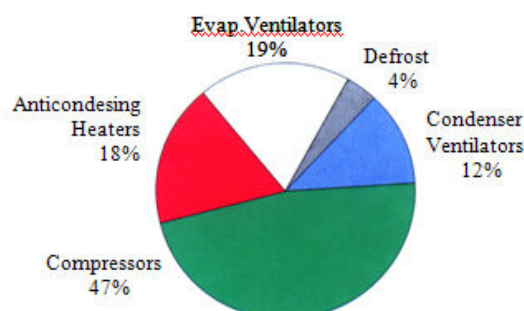


Figure 6 – Refrigeration equipment energy consumption [5]

The second line of action – trying to reduce electric consumption using more efficient systems – is maybe the easiest and more realistic way of acting at short term in refrigeration systems of supermarkets. In this field many things can be made to achieve the purpose of optimising the installation and reduce electric consumption. First, we can try to use more efficient equipment, namely evaporators, condensers, pumps and above all more efficient compressors. It is known that usually the compressor is the greatest source of electric consumption in the refrigeration systems. So, it should be our goal to choose not only the most efficient compressors, but also try to step the capacity of the refrigeration central using a correct number of compressors, and also if possible, using different capacities in the individual compressors that compose the central. This will increase the number of possible steps capacity, due to an optimised combination of the compression work. In some systems it is interesting also to use scroll compressors instead of alternative ones. This is more interesting when we can use capacity variators namely with variation in velocity of rotation. This variation of velocity of rotation it is possible also in some pumps.

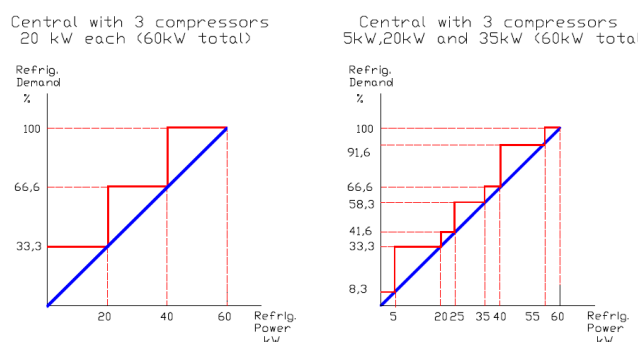


Figure 7 – Comparison of refrigeration power using different step capacities of compressors

Another important item that we can try to reduce to achieve energy savings in our installation is trying to use more efficient isolations. This is especially important if we work with very low temperatures namely in ultra-freezing systems and freezing tunnels. There are two items that we can consider the isolation of the cold stores and acclimatized rooms and the isolation of the piping. So, it is important to choose correct isolation materials, correct isolation thickness and correct construction and application of these isolations.

We can also try to use more efficient refrigeration fluids. Not only by optimising the type of refrigerant in use related with the evaporating and condensing pressure, working temperatures and refrigeration capacity, but also studying the possibility of using two fluids (one primary and one secondary) in our system. To eliminate refrigerant leaks is one of easiest ways of reducing energy consumption but it is also one of the most efficient. Some studies made in the sector of food and drinks [4] permit us to estimate a medium value between 1% and 15% of losses due to leaks, in refrigerant piping and others. A very important measure that can be made to reduce energy consumption is the implementation of heat recovery in the refrigeration systems. This is even more interesting when can be conjugated with other systems existing in the hypermarket. One example is the utilisation of heat recovery in refrigeration is the usage of hot gas leaving the compressor to pre-heating water to sanitary hot water usage. Other example is the utilisation of high pressure hot gas leaving compressor to defrost evaporators. Also the implementation of thermal accumulation in some times attractive namely one it is possible to produce cold energy at periods when compressors operation are more efficient. Nevertheless, this measure needs to be very well studied, because some time conduces to reduction in overall efficiency of the global installation.

Optimizing installation layout is other very important measure that can help us achieving energy savings in our refrigeration system. In fact a correct layout design of our hypermarket, should consider the grouping together of the cold store refrigeration areas [5], the minimisation of paths that the refrigerated goods need to pass through, the minimisation of distances of piping, and the optimisation of the localisation of refrigeration centrals and condensers. The optimisation of

working parameters is another very important tool to achieve energy savings. Two of the most important parameters that are possible to optimise are the condensing pressure and the aspirating pressure. In condensing pressure instead of keeping it in a fixed value (like the design value) it's very efficient to vary it as a function both of the exterior temperature and the instant charge of the installation. That is possible by varying the velocity of rotation of the condenser ventilators or by varying the number of condenser ventilators in use. Also in the evaporating pressure instead of keeping it in a fixed value it is possible to vary it using electronic expansion valves associated to an efficient control system. So, a optimised set of working parameters will be the conjugation of both reducing to minimum the condensing pressure and maximise the aspirating pressure in every moments of installation work. This will permit to achieve the minimum value of energy consumption in compressor due to compression work.

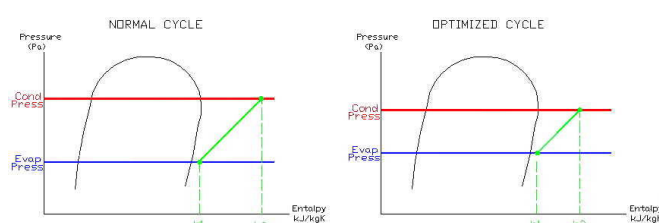


Figure 8 – Comparison of work in compressor with and without optimised parameters

Another very important aspect when we talk about energy savings in hypermarkets is the possibility of using velocity variators in mechanical equipment, namely compressors, pumps and ventilators. The basic principle is simple, when we have a variation in the solicitation charge of our mechanical equipment, we can vary is velocity of running to adapt the equipment to the demand, trying that the equipment work near his maximum efficiency. This is possible namely using frequency variators when electric motors are prepared to that. With this action we can also achieve more stable working temperatures and pressures, and lower levels of noise. A recent improvement in our goal of optimising the operation of refrigeration systems is the possibility of implement specific systems that monitories and control our installation. With these, we can define a group of working parameters that can be adapted to minimise energy consumption, namely working temperatures and pressures, defrosts, alarms, working hours and others. Finally, it is very important to keep our refrigeration system with efficient operation and maintenance during his lifetime.

TABLE I
ENERGY SAVING STRATEGIES IN REFRIGERATION SYSTEMS

Replace Electric Energy	More efficient Systems
Absorption systems	More efficient equipment's (compressors, evaporators, condensers, etc)
Adsorption systems	More efficient isolations (cold stores, acclimatized rooms, pipes)
Solar energy	More efficient refrigeration fluids (primary, secondary)
Wind energy	Eliminate refrigerant leaks
Geothermal energy	Implementation of heat recovery
Sea energy	Implementation of thermal accumulation
	Optimise installation layout
	Use correct capacity stages
	Use optimised working parameters
	Use velocity variators
	Implement systems that monitor and control the installation
	Efficient operation and maintenance of installation

III. A THE MONITORING STUDY

A monitoring study of energy consumption was made in a large hypermarket in a Portuguese city (Almada) nearby Lisbon. The hypermarket named Jumbo de Almada owned by the Auchan Group is located inside the Forum Commercial Centre, is the 14th Auchan hypermarket opened in Portugal, has a total selling area of 11000m² and represents an investment of 34 millions of euros.

TABLE II
JUMBO ALMADA IN NUMBERS

Total area of construction	21.695m ²
Total selling area	11.000m ²
Stocking area	4.773m ²
Number of cashiers	56 + 15
Parking places	5.000m ²
Number of collaborators	650m ²
Investment	34 millions euros



Figure 9 – Jumbo de Almada



Figure 11 – Jumbo de Almada layout with refrigeration equipment

The owner of the installation wanted to know if some purposes made in the time of the project's installation were correct and how far was the performance of the refrigeration installation from this plans. They wanted also to know how the refrigeration energy consumption in this hypermarket was. The refrigeration substructures are formed by 7 cold stores (Freezing), 17 cold stores (Refrigeration), 18 Acclimatized working rooms, 118 Refrigeration display cases, 43 Freezing display cases and 1 ice machine (3000 kg/day).

TABLE III
JUMBO ALMADA REFRIGERATION INSTALLATION

Freezing cold stores	7
Refrigeration cold stores	17
Acclimatized rooms	18
Refrigeration display cases	118
Freezing display cases	43
Ice machine	1



Figure 12 – Working room

The refrigeration system used in Jumbo de Almada is a vapour compression cycle using R404A with three subsystems, one for the refrigeration cold stores, one for the refrigeration display cases and one for the freezers (cold stores and display

cases). Each subsystem is composed by one refrigeration central with three or four alternative or scroll compressors, one feeding piping, two or three condensers and the respective number of evaporators with electronic expansion valves. The defrosting is by hot gas in the freezers and by stoppage in the refrigerators. The refrigeration installation is monitored and controlled by the Adap-kool Danfoss system.

TABLE IV
JUMBO ALMADA REFRIGERATION EQUIPMENT

	Ref Cap	N	Type	Ref.
Refrigeration central (display cases)	300 kW (-18°C/+40°C)	3	Scroll	R404A
Refrigeration central (cold stores)	202 kW (-15°C/+40°C)	3	Alternative	
Freezing central (cold)	132 kW	5	Alternative	



Figure 13 – Refrigeration machine room



Figure 14 – Condensers located in roof

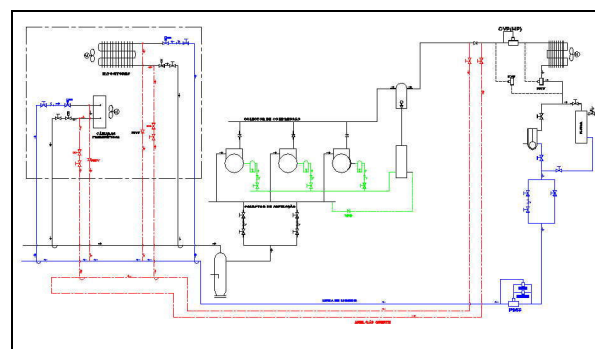


Figure 15 – The refrigeration scheme (freezing circuit)

This monitoring study as made in two different periods (January and July), corresponding to winter and summer working conditions. In these periods each refrigeration central was monitored, and the values of electric energy consumption and refrigeration capacities were registered. In each period of one week, two operating conditions were tested – running of the refrigeration installation with optimized parameters and running of the refrigeration installation with fixed design parameters. The time periods and working parameters considered are shown in table 6.

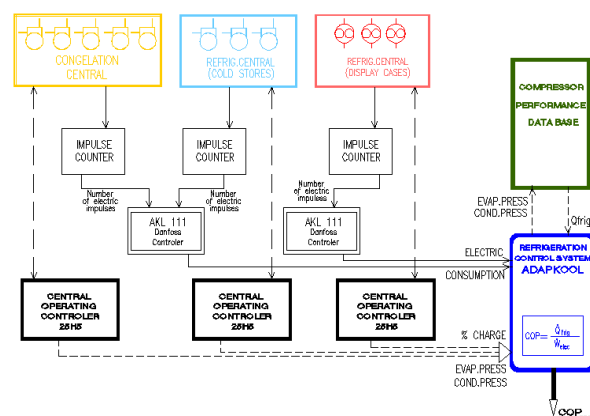


Figure 16 – The design of the monitoring system

TABLE V
THE MONITORING STUDY

Period	Type of func.	Cond. Pressure	Evap. Pressure	Expansion Valve
31/01 to 07/02	Conventional	Fixed 40°C	Fixed (-15°/-18°/-39°)	Fixed 8°-12°C superheat
07/02 to 14/02	Optimise	Variating	Variating	Optimised (min 3°C)
30/06 to 07/07	Conventional	Fixed 40°C	Fixed (-15°/-18°/-39°)	Fixed 8°-12°C superheat
07/07 to 14/07	Optimised	Variating	Variating	Optimised (min 3°C)

During this one week periods the values of electric consumption of each refrigeration central were registered, using an impulse counter and an AKL111A Danfoss controller, associated with the Adap-kool Danfoss control system. The values of the refrigeration capacity in each

moment were obtained through of the values of the condensing pressure and

Evaporating pressure, the values of the level of compressor's usage in each moment and the performance curves of each compressor. Finally, the value of real Coefficient of Performance (COP_{real}) was obtained using the values of

electric power consumption and refrigeration power capacity using the [6] formulae:

$$COP_{real} = \frac{\dot{Q}_{evap}}{\dot{W}_{elec}} \quad (1)$$

IV. RESULTS

A complete set of data results were obtained with this monitoring study. The values of condensing pressure, evaporating pressure, compressors capacity, exterior temperature, capacity of condensers, electric energy consumption, instant electric power and COP, were recorded each five minutes. After this registration, integration and mean data values were calculated. Some of the obtained results are shown in figures 15 to 18. In this graphs we can see the values of the real COP obtained by formulae (1) for the situations of summer operating conditions. The values of COP are shown in the vertical axis, for all week data (horizontal axis). A resume of the obtained results are also shown in table 7 and 8.

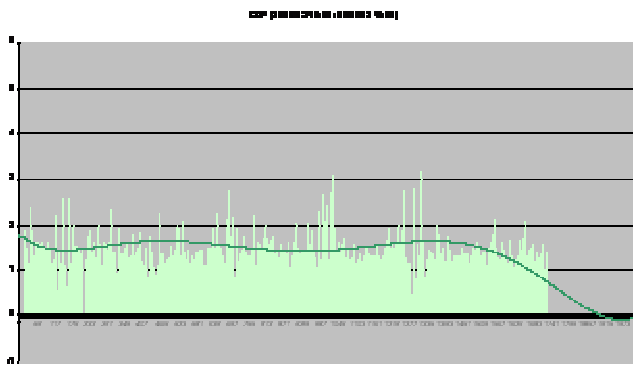


Figure 15 – COP screw compressors central conventional operation

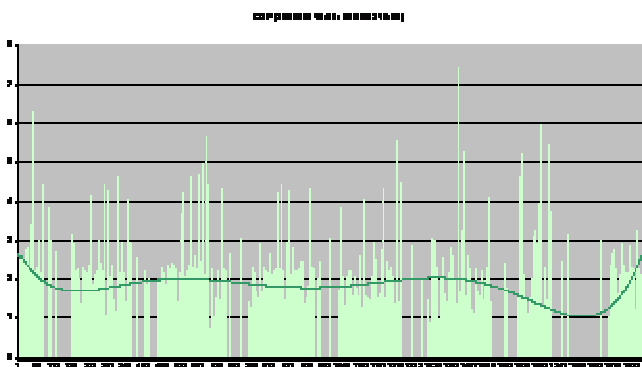


Figure 16 – COP alternative compressors central conventional operation

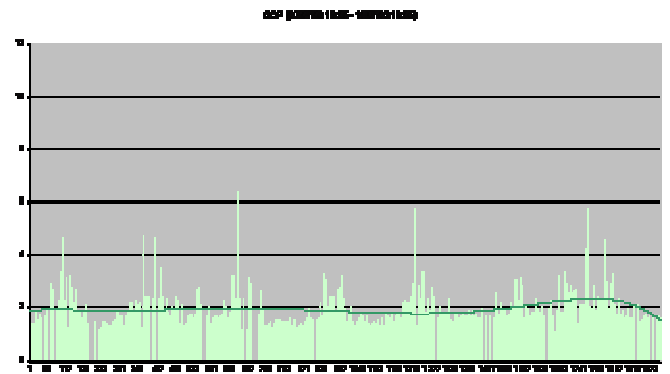


Figure 17 – COP screw compressors central optimised operation

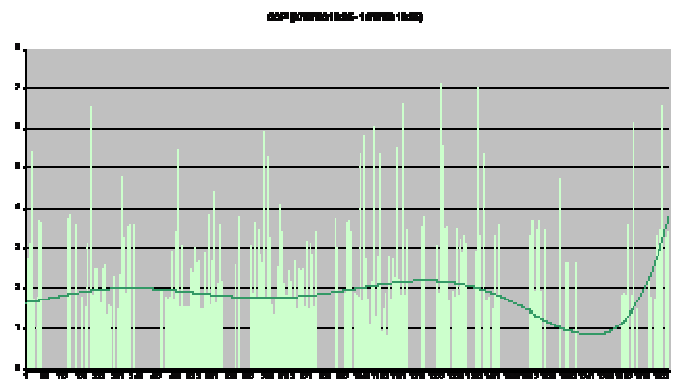


Figure 18 – COP alternative compressors central optimized operation

(mean values)

TABLE VI
RESUME OF OBTAINED RESULTS (WINTER)

	Cong. Central conventional	Cong. Central optimised	Ref. Display Central conventional	Ref. Display Central optimised	Ref. Cold stores conventional	Ref. Cold stores optimised
Compressors (num-type)	5 alternative	5 alternative	3 scroll	3 scroll	3 alternative	3 alternative
Evap. Temp (°C)	-39,1	-36,5	-16,9	-11,8	-16,7	-7,3
Comp. Capac (%)	60,2	51,0	52,7	36,8	30,6	19,2
Cond. Temp (°C)	36,3	23,7	38,7	26,2	35,4	23,2
Ext. Temp (°)	16,1	14,9	20,7	17,5	15,8	15,1
Instant Elect.Power (kW)	56,2	46,1	108,9	72,6	26,0	18,7
Refrig. Capac (kW)	80,7	75,8	169,2	177,8	67,7	56,5
COP real estimated (kW)	1,43	1,64	1,55	2,45	2,6	3,1

(mean values)

TABLE VI
RESUME OF OBTAINED RESULTS (SUMMER)

	Cong. Central Conventional	Cong. Central optimised	Ref. Display Central conventional	Ref. Display Central optimised	Ref. Cold stores conventional	Ref. Cold stores optimised
Compressors (num-type)	5 alternative	5 alternative	3 scroll	3 scroll	3 alternative	3 alternative
Evap. Temp (°C)	-38,9	-35,0	-17,4	-13,5	-14,3	-9,4
Comp. Capac (%)	62,8	54,1	77,4	66,6	46,4	36,4
Cond. Temp (°C)	39,4	30,3	40,5	35,2	39,4	30,9
Exterior. Temp (°)	24,1	24,2	22,6	22,9	25,4	25,9
Instant Elect.Power (kW)	60,7	55,1	154,5	136,1	44,1	38,5
Refrig. Capac (kW)	83,4	83,6	233,6	238,8	97,7	89,1
COP real (kW)	1,37	1,5	1,5	1,75	2,2	2,3

By the analysis of the obtained results we can conclude that in a general matter the installation is operating under very satisfactory conditions. We can also conclude that a correct choice of the optimised parameters conduces to a higher value in the COP of the refrigeration centrals. It is also visible that, the centrals operation under optimized conditions (variation of condensing pressure and evaporating pressure) permit to achieve higher COP's, reduces the electric energy consumption and reduces the number of working hours in compressors, than the conventional working conditions. It is also visible that in a general way the alternative compressors central (refrigeration cold stores) achieve higher COP's than the screw compressor one (refrigeration display cases). This could possible change if we use 100% capacity variations instead of three steps capacity variation in the screw compressors central.

V. CONCLUSIONS

A set of energy saving strategies to refrigeration installations were presented and discussed. Some examples of vantages and disadvantages of some of these strategies were described. Particular importance was given to the usage of more efficient equipment, more efficient isolations, more efficient refrigeration fluids. The importance of eliminate refrigerant leaks was also discussed. Other strategies like the implementation of heat recovery, thermal accumulation, and optimizing installation layout were also refereed. Special importance was given to some operating aspects like the usage

of correct capacity stages, the usage of optimized working conditions and velocity and capacity variations, and efficient installation monitorize and control systems. Finally an example of a monitoring study realized in a real hypermarket (Jumbo Almada) was presented and discussed.

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