Electronic Expansion Valves Vs. Thermal Expansion Valves

By Renato Lazzarin, Daniele Nardotto, and **Marco Noro, Ph.D.**

Storing cold and frozen foods uses approximately 40% to 50% of electricity in supermarkets. Open vertical display cabinets, in particular, are large users of electrical energy.

Many refrigerating machines use thermostatic expansion valves (TEVs). TEVs are the most widespread expansion device, but they have some characteristics that can limit versatility and performance of the machines. For example, this valve requires a minimum pressure drop between condensation and evaporation. This prevents possible advantages of low condenser pressure for air-cooled condensers. A minimum amount of superheating must be provided to avoid possible hunting of the valve.

Some plants are more sensitive to negative aspects of TEV regulation because of plant specifics, type of duty, or distribution of cooling load during the year. Refrigerating machinery in supermarkets is just a characteristic example.

One solution to the problems of TEV is the electronic expansion valve (EEV). This electrically driven control device has been studied experimentally and theoretically in recent years,[1,2,3] and it is widely available. It controls the refrigerant flow at the evaporator by means of a pressure sensor and a temperature sensor, which are both at the outlet of the evaporator. The two signals are elaborated by a regulator that controls, in real-time mode, the valve opening.

To evaluate the possibilities of using EEV versus TEV, a large supermarket located on the Tirrenic coast of Italy, not far from Pisa in North Italy, was retrofitted with the EEVs installed in parallel to the TEVs to operate the plant alternately with the two technologies.[4] A simulation model was developed to compare the two technologies on an annual basis from the energy and economic point of view under different conditions. The comparison was made for three climates: Milano, Roma and Trapani (for which hourly test refer-

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ence year data are available[5]) to investigate the behavior of the system when varying the condensation conditions.

Refrigeration System

The supermarket refrigeration system is divided into two independent circuits: low temperature (T_{ev}= –34°C [–29°F]) and medium temperature (T_{ev}= –13.5°C [–29°F]) with, respectively, 75 kW and 325 kW refrigerating capacity. The refrigerant is R-404A, and its condensation is provided by two rooftop condensers: three units for medium-temperature circuit and one unit for low-temperature circuit (476 kW, 21.4 m^3/s [45,360 cfm] for each unit). Refrigerating and heat rejection capacities have to be considered as nominal powers. The retrofit solution involved the creation, in each display cabinet, of two parallel expansion lines: one with a TEV and the other with an EEV, which are activated alternately by solenoid valves on a daily basis. This allowed comparative tests to be carried out between the two systems in the same environmental and load conditions (*Figure 1*). A remote machine room hosts the compressors (three per circuit) that work in parallel with an inverter-based control system. Suction pressure is set at a fixed value (0.35 MPa [3.5 bar] and 0.15 MPa [1.5 bar], respectively for medium-temperature and low-temperature circuit, for both TEV and EEV), while the minimum head pressure is regulated at (nearly) 1.6 MPa (16 bar) for TEV and 1.2 MPa (12 bar) for EEV (condensation setpoint is followed by varying fans turning speed).

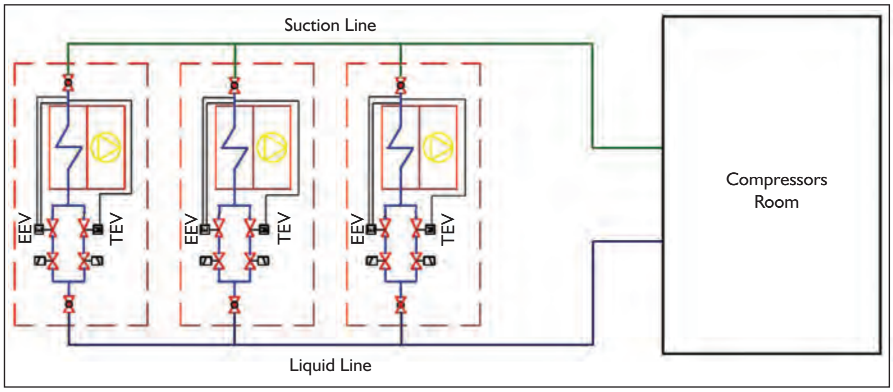

Figure 1: Refrigeration system: machine room layout.

Desuperheating of the refrigerant allows heat recovery: two heat exchangers in low-temperature circuit (for the tap water circuit and for space heating) and one heat exchanger in medium-temperature circuit (only for space heating).

Energy Analysis

A one-year experimental survey started in April 2004. Data was logged and recorded (outdoor and indoor air dry-bulb temperatures, total electrical consumption, state of compressors, fans and drivers, thermophysical properties of refrigerant, heat recovery by means of magnetic volumetric flow rate meters and PT100 thermoresistances placed on water circuits, etc.) with a small time interval (varying from 5 to 120 seconds depending on the variable).[4]

The annual experimental results reveal an important advantage in using EEV in this application instead of TEV. In fact, the same service was provided for the medium-temperature circuit, requiring 1 529 433 MJ (424,746 kWh) of electricity using EEV and 2 589 989 MJ (719,278 kWh) with the TEV. These needs are the projection for the whole year, i.e., the measured energy is half the reported because each system operated every other day. The possible saving with the low-temperature circuit is less remarkable, but quite relevant. EEV required 1 063 142 MJ (295,250 kWh) versus 1 430 914 MJ (397,386 kWh) of TEV.

This article discusses the superiority of EEV in this application for the climate where this experiment was performed. To study the possible results in other climates, the influence of the outside temperature on the possible performance of the two systems must be analyzed. Because the display cabinet's refrigerating load cannot be exactly predicted due to several stochastic reasons (refrigerating capacity is strongly influenced by customer frequency, by thermal and physical characteristics of the packaged goods and by internal gain of the building), electrical consumption of compressors as a function of outside air temperature is difficult to estimate on the basis of recorded data. Instead of developing a formula based on recorded data, it has been preferred to calculate compressors' power consumption on the basis of the thermodynamic cycle by means of a well-known refrigeration cycles' modeling software, assuming, for the two circuits and for the two kinds of valves, the hypotheses is summarized in *Table 1*. The cycle's behavior with EEV has been simulated by using a lower superheating (*Table 1*) and a lower condensation pressure than TEV. The values used in the simulation were inferred by recorded experimental data. Condensation temperatures for EEV and TEV have been considered about 10°C higher than outside air temperature. Previously reported annual consumption data and information about measurements as shown in *Figure 1* are work well for checking the reliability of the predicted annual energy savings, depending on the climate.

The results of the simulations are depicted in *Figures 2* and *3*, where P_{el} of compressors is the specific power per unit of refrigeration capacity. Note that for outside air temperature higher than 37°C to 38°C (99°F to 100°F), the two curves (in both circuits) intersect. Under these conditions, EEVs provide no energy advantages with respect to TEVs. This result agrees with previous works,[6,7] where a high energy savings was claimed (due to the great modulation and adjustment capability of EEV with respect to TEV) at low condensation pressure (that implies low outside air temperature), while energy saving is decreasing with the increasing of condensation temperature. This is directly connected to a refrigerating capacity increase of the cabinets with EEV because of:

- Higher refrigerant mass flow rate for lower condensation pressures;
- More steady operation; and
- Lower superheating of the refrigerant at the evaporator outlet.

These and other factors (i.e., the different behavior of the condenser fans or the greater number of transient periods with TEV with respect to EEV) justify energy savings to exist immediately just below 37°C to 38°C (99°F to 100°F).

Note also that a further decrease of the outside air temperature below 10°C to 15°C reduces possible energy savings. This is due to the decreasing slope of the saturated liquid refrigerant curve at a lower temperature. (In the low-temperature circuit, *Figure 2*, the two curves would intersect at lower temperatures with respect to medium-temperature circuit, *Figure 3*, because of the minor evaporation temperature, see *Table 1*.)

Savings are higher with medium-temperature cabinets than low temperature ones, reaching almost 40% in the range of 10°C to 20°C (50°F to 68°F) outside air temperature. This is due to medium-temperature circuit greater sensitivity to outside air temperature because of lower compression rate of the thermodynamic cycle than low-temperature circuit.

Annual energy savings depend strongly on the climate. An annual simulation was carried out for three climates: Milan (North Italy with a temperate, cold climate), Rome (Central Italy with a mild climate), and Trapani (South Italy with a hot climate). To characterize the climates, *Figure 4* reports the temperature distribution all year long. Trapani has the hottest climate, although not torrid (as the town is situated at the seaside), where Milan and Rome present longer periods (of limited extension) at temperatures below 30°C (86°F).

Table 2 reports the annual electrical consumption and heat recovery for all 118 cabinets of the supermarket and for the three climates analysed (as written in the previous paragraph, desuperheating heat is recovered by heat exchangers in the two circuits for tap hot water and for space heating). Values are expressed in terms of primary energy (in MJ), taking into account an electrical efficiency production of 0.4 and a thermal efficiency production of 0.9 of the natural gas boiler used to provide the same quantity of heating energy.

In *Table 2* only the compressor consumption is considered. Electrical consumption of condenser fans is higher with EEVs. Condenser fans operate even at low outside temperatures; however, they do not with TEVs. The fans' electrical power is less than one-tenth of the compressors'. Fan consumption was not recorded, but a rough estimate that the overstating of EEV benefits with respect to TEV neglecting the fans is definitely less than one-tenth and probably one-twentieth of the savings listed on the table. For this application, there are other electrical consumptions linked to the

	Low Temperature		Medium Temperature	
	TEV	EEV	TEV	EEV
TEV (°C)	–34	–34	–13.5	–13.5
Superheating (°C)	10	5	14	14
Subcooling (°C)	20–17	10–9.5	5–4	3–1
Isentropic Efficiency	0.85–0.73	0.85–0.78	0.85–0.70	0.85–0.75
Pressure Drop at Suction and Discharge Lines (°C)	0.5	0.5	0.5	0.5

***Table 1:** Hypotheses of the thermodynamic cycle for the calculation of the specific compression power. Subcooling and isentropic efficiency are considered decreasing in the respective ranges, increasing the condensing (and so outside air) temperature.*

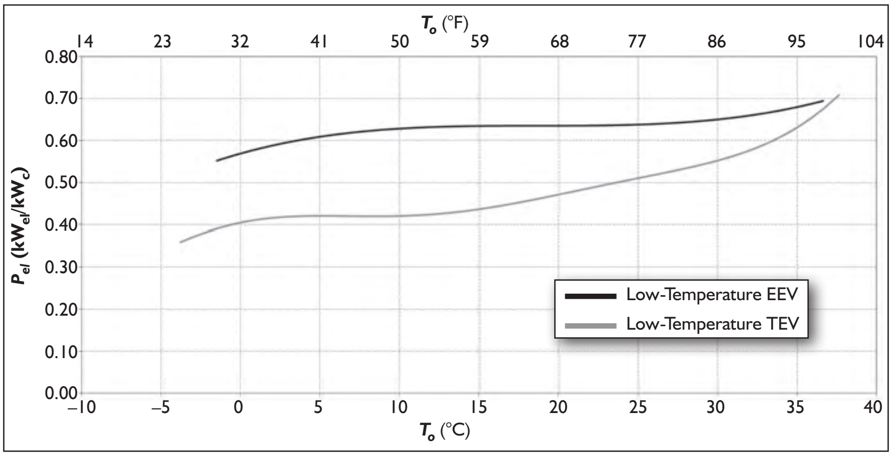

***Figure 2:** Low temperature—electrical consumption. Specific electrical power consumption of compressors for the low-temperature circuit, both for thermostatic and electronic expansion valves as a function of outside air temperature.*

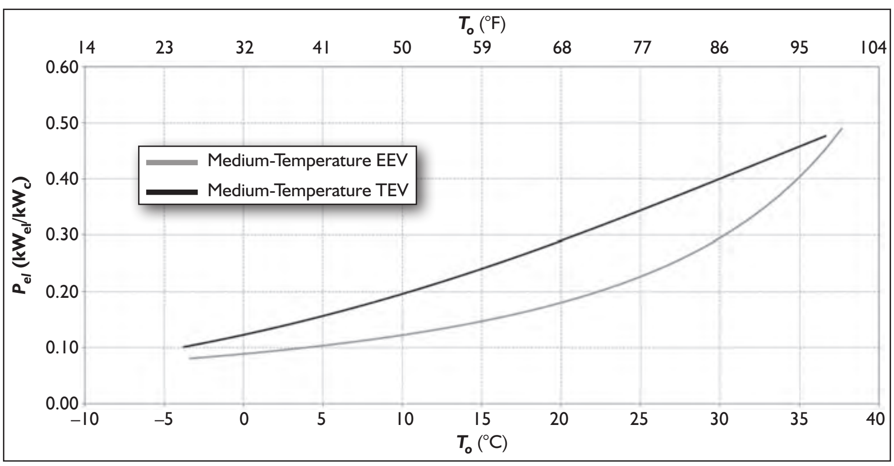

***Figure 3:** Medium-temperature—electrical consumption. Specific electrical power consumption of compressors for the medium-temperature circuit, both for thermostatic and electronic expansion valves as a function of outside air temperature.*

operation of the plant, called "auxiliaries," such as evaporator fans, antimisting resistors, cabinet lights, etc. These are quite constant with EEVs and TEVs. They can be neglected in PES calculation.

Electrical consumption for the compressors has been calculated by multiplying the values of *Figures 2* and *3* by the total cooling capacity of the two circuits (respectively 75 and 324 kW) and by the number of hours for each outside air temperature value. They are in good agreement with experimental data.[8] The values increased from Milano to Trapani, for low- and medium-temperature circuits, but more for the latter in relative terms. In fact, as written before, the sensitivity to the climate is higher for medium temperature connected to the stronger influence of a different condensation temperature in the smaller temperature difference of medium temperature.

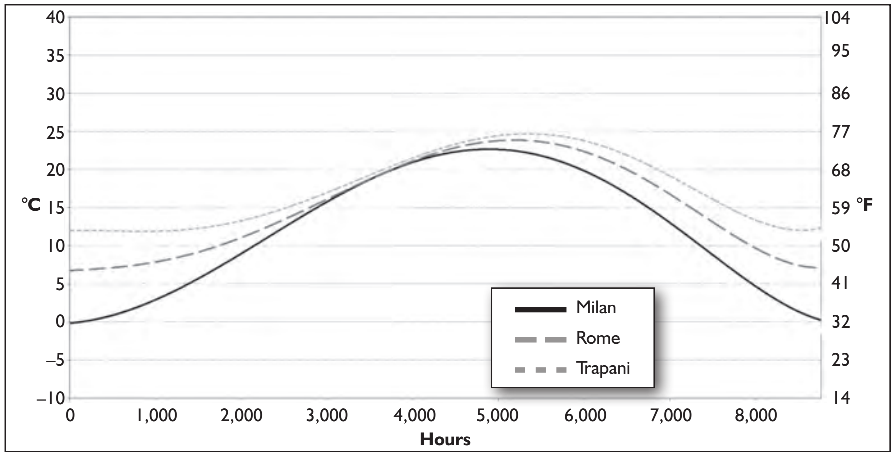

***Figure 4:** Outside air-temperature distribution for the three considered climates (regression of hourly data).*

Heat recovery (obtained by means of regression functions on the basis of experimental data[8]) increases from colder to milder climates (due to a larger number of hours with higher outside air temperatures, therefore, with higher refrigerant condensation temperatures).

In terms of primary energy saving (the last three columns in *Table 2*), consider that TEV allows a higher heat recovery (and therefore the item is negative), because of the larger quantity of heat recoverable with TEV due to the higher condensation pressure with outside air temperature lower than 37°C to 38°C (99°F to 100°F) (by far the most frequent condition for all the three climates). It is worth remembering that the higher condensing pressure with the TEV is due to the constraint of a higher pressure differential across the TEV that provides proper refrigerant flow control.

Considering all the energy elements (compressors, condenser fans, auxiliaries, and heat recovery), *Figure 5* reports the primary energy saving for the three climates. Note that, for this application, total PES for compressors consumption is around 36% for Milano, and decreasing to 29% for the milder city of Trapani. Considering all the electrical consumption (power and auxiliaries), energy saving is respectively 22% and 18.5%. It does not suffer too much of the greater heat recovery with TEVs for this particular application (PES decreases only by 1% taking into account heat recovery).

An Economic Evaluation

The previous analysis demonstrated an energy advantage of the system equipped with EEV in this application for hot climates, an economic analysis is necessary to assess the real profit of the replacement of the valves in an existing plant. The parameters to be fixed are the investment costs, the unitary cost of electricity, and the discount rate for the investment. Another parameter is the useful life of the investment. The payback period is far shorter than the expected life of the equipment.

Investment costs of the innovative system were obtained on the basis of the costs met in the retrofitting of the supermarket excluding the costs of monitoring. Total cost is composed of components (mainly EEVs) and labor. The cost of the EEV solution is approximately $445 for each of the 118 display cabinets in the studied supermarket. This results in a $52,450 total investment cost for the plant. Total cost is lower when EEVs are directly installed by cabinet manufacturers.

Electrical energy cost is fixed at $0.127/kWh, interest rate at 5% and an investment period of 15 years. *Table 3* reports the results of the economic analysis for the "base case" described above, in terms of annual savings, net present worth (NPW), and discounted payback period (DPP). Because the NPW is always positive, investment is advantageous for all the climates. Initial costs are recovered in a short time period, about 1.4 years for Milano and a little more for the other climates.

A sensitivity analysis can illustrate the possible results for parameter values diverging from the previous hypothesis. An increase of 50% in the investment cost slightly influences the profit of the intervention just as a doubling of the interest rate. The most influential parameter is the electricity tariff, where halving that would roughly double the payback period (doubling the tariff would halve the payback period). This would not alter the overall advantage even if you do not consider a probable increase of the tariff with time.

Conclusions

Using EEV technology with display cabinets of a large supermarket demonstrated considerable energy savings due to the superior control characteristics of the EEV and the favorable type of application, (operating conditions in which the condensing temperature is allowed to drop with the outdoor temperature). A simulation model demonstrated that similar advantages are possible under different climate conditions. For this particular case, with heat recovery on desuperheating of refrigerant, only a slight penalization is introduced. As the required investment cost is not particularly high, energy savings also allow important economic savings and a short payback period (1.5 years and probably shorter if EEVs are installed directly by cabinet manufacturers). It is surprising that such a small piece

	Low-Temperature EEV		Low-Temperature TEV		PES		
	Compressors	Heat Recovery	Compressors	Heat Recovery	Electrical	Heat Recovery	Total
MI	2,619,294	365,315	3,670,574	552,605	1,051,280	–187,290	863,990
RM	2,702,324	366,920	3,737,550	575,875	1,035,226	–208,955	826,271
TR	2,769,102	368,128	3,765,236	580,584	996,134	–212,456	783,678
	Medium-Temperature EEV		Medium-Temperature TEV		PES		
	Compressors	Heat Recovery	Compressors	Heat Recovery	Electrical	Heat Recovery	Total
MI	3,446,230	479,841	5,737,701	675,857	2,291,471	–196,016	2,095,455
RM	4,197,532	493,130	6,353,658	696,074	2,156,126	–202,944	1,953,182
TR	4,749,422	498,569	6,850,745	707,660	2,101,323	–209,091	1,892,232
	EEV (Low Temperature + Medium Temperature)		TEV (Low Temperature + Medium Temperature)		PES (Low Temperature + Medium Temperature)		
	Compressors	Heat Recovery	Compressors	Heat Recovery	Electrical	Heat Recovery	Total
MI	6,065,524	845,156	9,408,275	1,228,462	3,342,751	–383,306	2,959,445
RM	6,899,856	860,050	10,091,208	1,271,949	3,191,352	–411,899	2,779,453
TR	7,518,524	866,697	10,615,981	1,288,244	3,097,457	–421,547	2,675,910

Table 2: Electrical energy for the compressors and heat recovery by refrigerant desuperheating for the two circuits (low temperature and medium temperature) for the three climates. On the last columns on the right are the primary energy saving using EEVs with respect to only electrical consumption, heat recovery and the total. Values are all expressed in megajoule and in terms of primary energy.

of equipment, which until now has been poorly innovated with respect to the other components of the refrigerator (compressor and heat exchangers) can offer such high savings. It is hoped that there will be a rapid replacement of TEVs in many refrigerating and HVAC sectors.

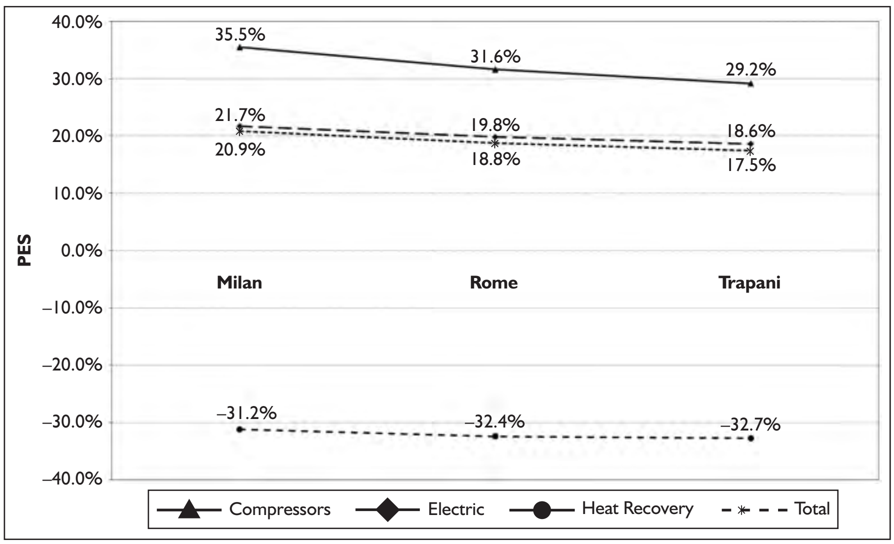

Figure 5: PES for the supermarket for compressors, electrical (compressors + condenser fans + auxiliaries), heat recovery and the total for the three climates.

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Investment Cost (US$/Year)	City	Annual Savings (US$/Year)	NPW (US$/Year)	DPP (Years)
52,451 (Base Case)	MI	40,120	363,979	1.4
	RM	37,457	336,345	1.5
	TR	35,955	320,750	1.6

Table 3: Annual savings, net present worth and discounted payback period for the three climates (base case).

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