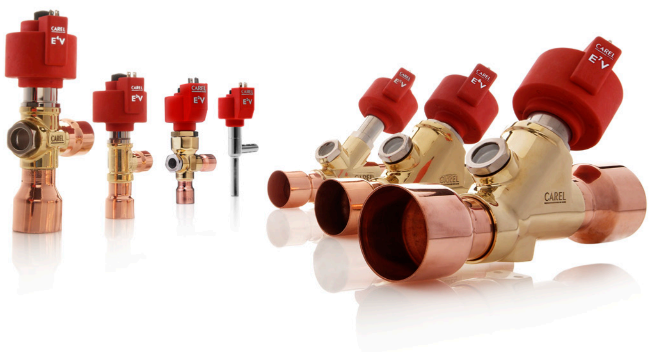
High
Efficiency
Solutions.

CAREL

application note

Electronic expansion valves reduce the significant energy losses due to cycling transients in refrigeration units with ON/OFF control.



where

CAREL INDUSTRIES HVAC/R applications laboratory
- air/water refrigeration unit on R410A

what

Analysis of refrigeration unit start-up
- evaluation of energy loss
- optimisation of start-up

why

Optimised refrigeration unit start-up is fundamental in increasing energy efficiency.

Electronic expansion valves - a solution to reduce energy inefficiency at start-up

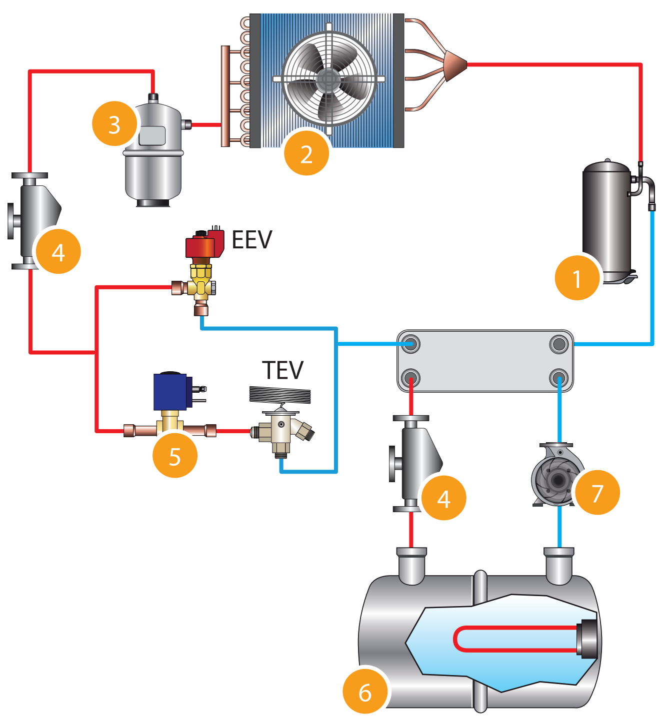
In both residential and commercial contexts, variable cooling demand often forces designers to install refrigeration units with higher capacities than the maximum expected cooling load.
Consequently, unit cooling capacity needs to be controlled.
This control can be implemented in two ways:
- using variable speed compressors that can deliver required cooling capacity instant-by-instant;
- using classic on/off operation

This second control mode, which due to its simple operating principle is still very widespread, is nonetheless affected by a series of energy inefficiencies at start-up.
The effects of these inefficiencies are often underestimated, however at times they may be significant.
This document describes how laboratory tests have been used to quantify the extent of such inefficiencies and demonstrate how using an electronic expansion valve can drastically reduce these.

Experimental testing

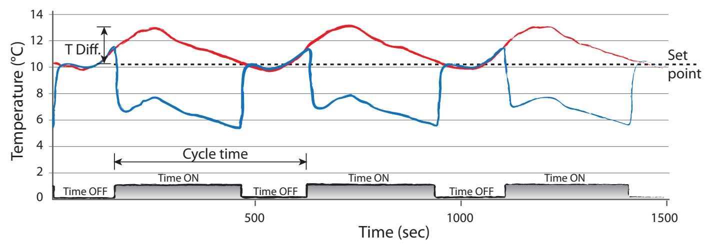
To analyse the phenomenon of energy losses at start-up, a refrigeration unit with a rated capacity of 6.8 kW and classic ON/OFF control was installed inside the HVAC/R applications laboratory.
A complete data acquisition system was used to monitor all the thermodynamic parameters that characterise the refrigeration cycle.
Several tests were conducted, lasting one hour each, varying the refrigerant charge and setting the unit so as to work alternatively:

- with a thermostatic expansion valve (TEV);
- with a thermostatic expansion valve and on-off solenoid valve in series (TEV*);
- with an electronic expansion valve (EEV).



1 *compressor*
2 *condenser*
3 *liquid receiver*
4 *flow meter*
5 *solenoid valve*
6 *storage with heaters*
7 *pump*

Temperature trend in an ON/OFF cycle



compressor status
water inlet temperature (°C)
water outlet temperature (°C)

Qualitative analysis of energy losses at start-up

Cyclical operation of a refrigeration unit is due to the difference between the capacity delivered by the compressor and instant demand.
This difference is itself a consequence of the variation in load over time, for example due to the time of day or season, as well as oversizing of the unit compared to average load, which as mentioned is a very common design practice.
The number of starts per hour is moderated by the thermal inertia of the system, therefore, in general terms, on-off cycle frequency is higher in smaller systems.

Each compressor shutdown / start-up transient involves a loss of energy.

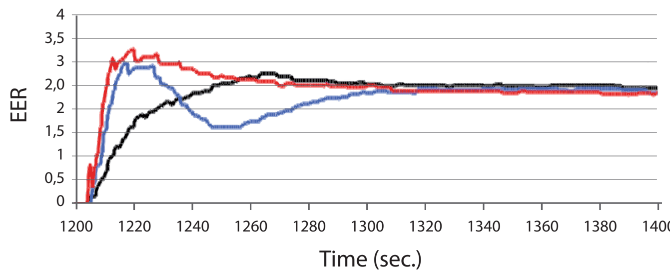
The tests conducted have allowed these energy losses to be explained and quantified, by measuring, in different operating conditions, the trend in EER (Energy Efficiency Ratio) over time, in other words, the ratio between cooling capacity delivered and compressor power consumption, in particular in the period just after the compressor starts.

The following two main conclusions can be drawn:

- **EER values in the instants just after each start-up were low in all the tests conducted:** this is essentially due to refrigerant leaving the evaporator in the liquid phase, which on reaching the compressor reduces efficiency (and indeed endangers operation). This phenomenon is caused by the migration of liquid refrigerant through the parts of the unit to the evaporator after the compressor stops, and imperfect control of the expansion valve which, during the initial transient, is subject to swings in operation. As all of these events occur every time the compressor starts, the energy expense increases as starts become more frequent;
- **EER values measured when testing with the electronic expansion valve were always higher than the values measured when using the thermostatic expansion valve, both with or without solenoid valve**: this higher energy efficiency is ensured by the capability of an EEV to optimise control of refrigerant flow in the evaporator, limiting the delivery of liquid into the compressor. In addition, like a solenoid valve, the electronic valve stops refrigerant flow when the compressor stops. This prevents liquid refrigerant from migrating to the compressor when this is off.

Consequently, an **electronic expansion valve** can drastically reduce energy losses due to refrigeration unit ON/OFF cycles.

Energy efficiency at start-up



electronic expansion valve
thermostatic expansion valve with solenoid valve
thermostatic expansion valve without solenoid valvee

Quantitative analysis of energy losses at start-up

Looking now at the quantitative analysis, an increase in power consumption due to inefficiencies was measured in the instants following start-up, when compared against an ideal case of continuous operation - which only occurs when system load matches the cooling capacity delivered by the compressor.

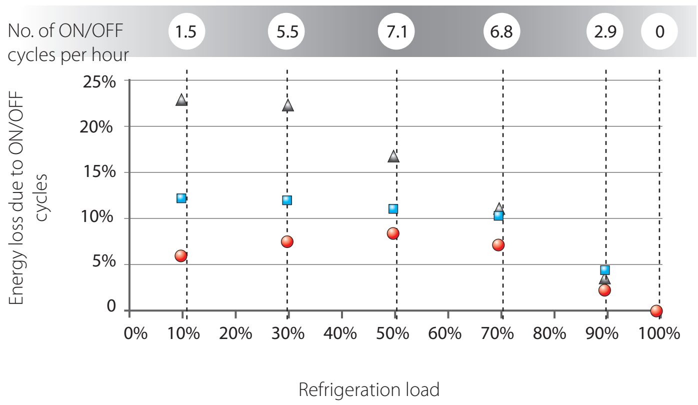
This analysis shows that in the case of operation with a mechanical thermostatic valve, without shut-off valve, inefficiencies may cause significant increases in power consumption, up to a maximum of 23% in the most unfavourable conditions.

Adding a solenoid valve to shut off refrigerant upstream of the mechanical thermostatic valve limits the increase in power consumption to a maximum of 13%.

Using an electronic expansion valve, finally, further reduces energy losses at start-up. The maximum extra power consumption compared the ideal continuous operation is in fact always less than 8%.

The maximum differences between the three systems tested occur at minimum load.

Energy losses as refrigeration load varies



- *electronic expansion valve*
- *thermostatic expansion valve with solenoid valve*
- *thermostatic expansion valve without solenoid valve*

Cost analysis

From an economic point of view, the comparison was made assuming:
- a unit with 20 kW cooling capacity for comfort applications, with an average refrigeration load of 50% and operating 3000 h/year;
- a unit with 10 kW cooling capacity for industrial applications, with an average refrigeration load of 50% and operating 5000 h/year;

For both units, the reference EER is 3.

Using the data summarised in the quantitative analysis, the average effective EER was calculated, seeing that this differs from the reference due to energy losses at start-up. Based on this, the annual power consumption of the various alternatives was evaluated (indicated as previously, TEV, TEV* and EEV), together with the consequent energy cost.

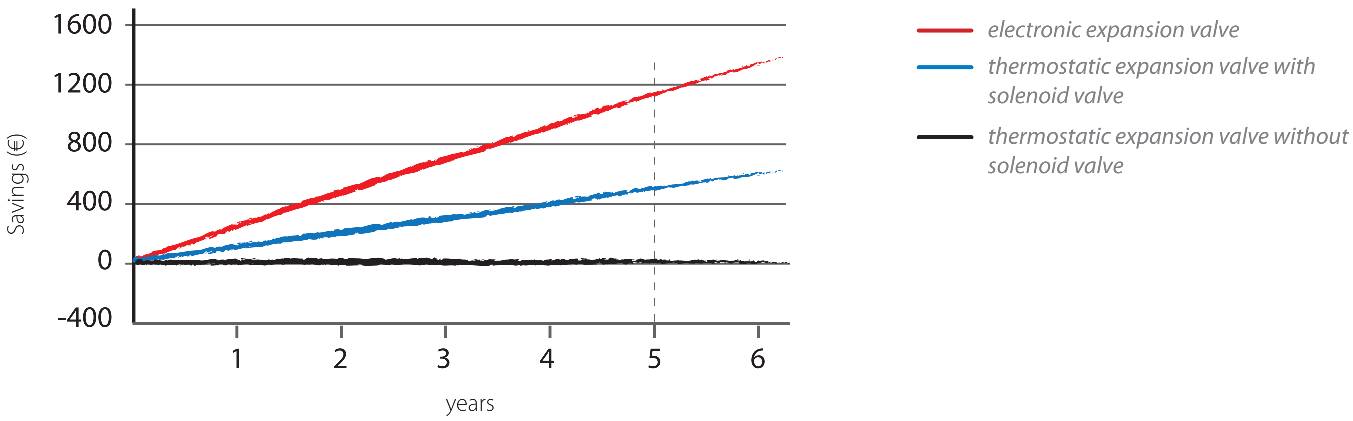
The cost analysis highlights how the solution with electronic expansion valve allows savings of around 220 €/year in comfort applications compared to a solution with thermostatic valve only.
Finally, considering that energy losses at start-up are proportional to installed cooling capacity, while the costs of components related to the use of the electronic expansion valves grow to a much lower extent, it is clear how this solution will have greater economic advantages on units with higher cooling capacity.

Cost analysis

description	UOM	TEV	TEV*	EEV
AIR-CONDITIONING unit				
Rated cooling capacity	kW	20	20	20
Average refrigeration load	kW	10	10	10
Rated EER	non-dim	3	3	3
Energy losses	%	17	12	7
Average effective EER	non-dim	2.56	2.68	2.80
Average power consumption	kW	3.90	3.73	3.57
Energy consumed for 3000 h/year	kWh/year	11700	11200	10700
Annual energy savings **	kWh	-	500	1000
Energy cost in Italy (2012)	€/kWh	0.22	0.22	0.22
Annual cost savings	€	-	110	220
Energy savings in 5 years	kWh	-	2500	5000
Cost savings in 5 years	€	-	550	1100
INDUSTRIAL unit				
Rated cooling capacity	kW	10	10	10
Average refrigeration load	kW	5	5	5
Rated EER	non-dim	3	3	3
Energy losses	%	17	12	7
Average effective EER	non-dim	2.56	2.68	2.80
Average power consumption	kW	1.95	1.86	1.78
Energy consumed for 5000 h/year	kWh/year	9750	9300	8900
Annual energy savings **	kWh	-	450	850
Energy cost in Italy (2012)	€/kWh	0.22	0.22	0.22
Annual cost savings	€	-	99	187
Energy savings in 5 years	kWh	-	2250	4250
Cost savings in 5 years	€	-	495	935

(**) referred to the TEV solution (with thermostatic expansion valve and without solenoid valve)

Cost savings in 5 years - AIR-CONDITIONING unit



Applications

The results of this study can be applied to a vast range of HVAC/R applications, including:

cold rooms

heat pumps

water chillers

Conclusions

The tests conducted at the CAREL INDUSTRIES SpA laboratories have confirmed the low operating efficiency of refrigeration units immediately after start-up.
This inefficiency can be drastically reduced by using an electronic expansion valve. This solution, if compared against the alternatives using a thermostatic valve, can bring clear savings in terms of both energy and costs.
In the specific case in question, compared against the solution with thermostatic expansion valve, inefficiency was reduced from a maximum of 23% to a maximum of 8% and, taking the example of a 20 kW refrigeration unit, this reduction in inefficiency means savings exceeding € 1000 over a 5 year period.

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