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DIRECTORATE-GENERAL ENERGY AND TRANSPORT

New Energies & Demand Management
Promotion of Renewable Energy Sources & Demand Management

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THE EUROPEAN PILOT
MOTOR CHALLENGE PROGRAMME

Refrigeration Systems Module

MOTOR CHALLENGE

Contents

1. Introduction to the Refrigeration Systems Module document

This document is subsidiary to the Motor Challenge Programme (MCP) "Partner Guidelines". It defines what an MCP Partner Action Plan should cover, if the Partner company's commitment includes Refrigeration Systems[1] (RS). In particular, it explains what a Partner does for each of the following steps of participation in the Challenge:

- **Inventory** of refrigeration components and system functioning
- **Assessment** of the applicability of possible energy saving measures
- **Action Plan**, presented to the Commission, which defines what the Partner has decided to do to reduce operating costs by improving energy efficiency
- **Annual report** of progress on the Action Plan.

Note that documents relating to the Inventory and the Assessment are in house, confidential documents, while the Action Plan and Annual Report are reported to the Commission.

This document covers all industrial refrigeration systems. A refrigeration system is defined as a system delivering heat at a temperature below 0°C. However forced cooling systems operating between 0 °C and ambient temperature are very common but are out of the scope of the module. However many measures described in this document for refrigeration systems are similar for forced cooling systems. Cooling systems operating above ambient temperature have to be treated separately.

2. Inventory of refrigeration components and system functioning

As a first step towards identifying applicable energy savings measures, an MCP Partner should establish an **Inventory** of his refrigeration systems components and major system operating parameters. The Inventory is established in 3 phases:
A (basic system description), B (documentation and measurement of system operating parameters) and C (global indicators of system performance).

A. Basic system description

Basic system description consists of consulting company records or carrying out simple measurements, in order to assemble the following data.

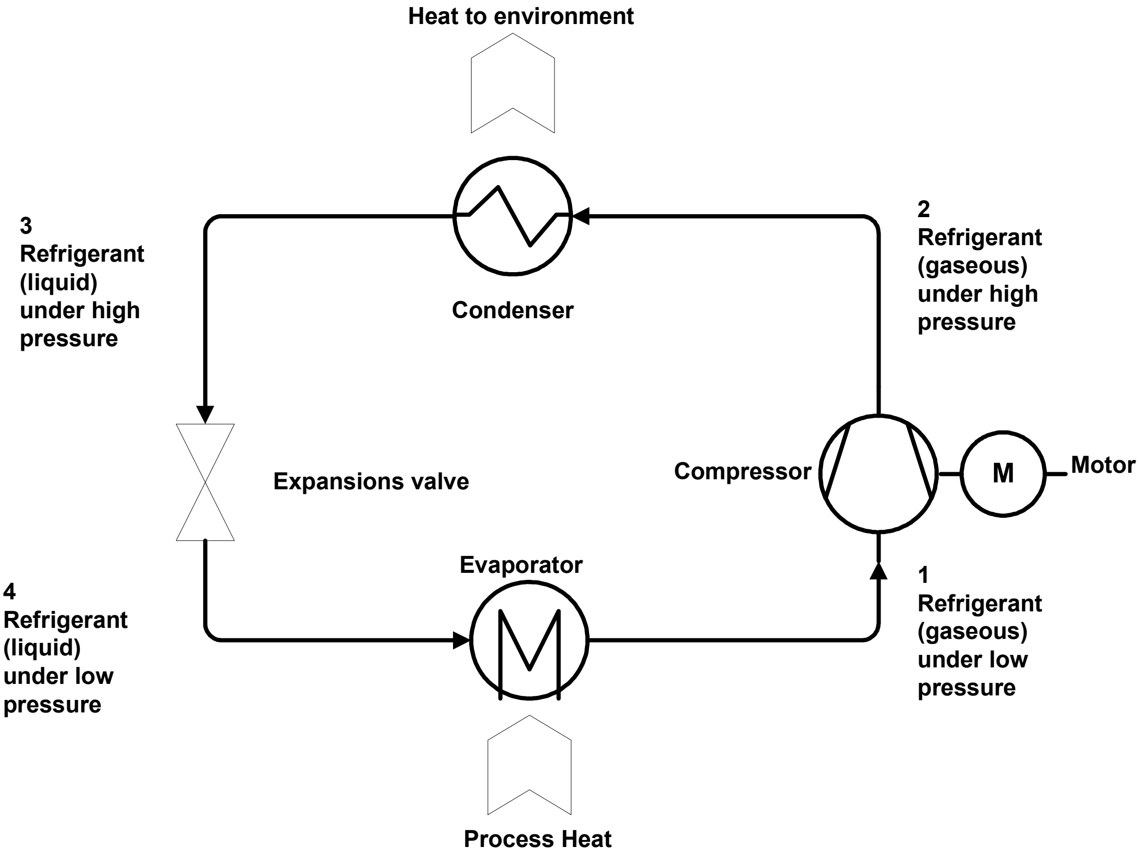
1. Equipment list and layout, stating main uses of refrigeration
2. Refrigerant use in the installation
3. End use temperature (point of use, minimum)
4. More than one temperature required?
5. Operating hours/year
6. Demand profile: estimated variation during day/week
7. Is system shut off when not needed?
8. Age of system components

[1] Refer to the "Partner Guidelines" for an explanation of terms such as "Partner", "Action Plan" and "commitment".

In many organisations, most or all of this data could be assembled by in house staff.

Refrigeration System

Refrigeration systems are widely used in industrial applications at present. Sectors with a high share of refrigeration systems are food industry, chemical industry and construction industry. Most refrigeration systems are based on the vapor refrigeration process using a refrigerant allowing a change from the liquid to the gas phase. The main components of a refrigeration system are compressor and condenser (see figure). Depending on the application the system can also comprises multiples condenser or compressors.



- **Evaporator:** In the evaporator a heat exchanger evaporates the refrigerant. Heat removed from the conditioned space within the evaporator causes the liquid refrigerant to evaporate at a very low temperature, producing a low-temperature, low-pressure gas.

- **Compressor:** This unit pulls the refrigerant gas from the evaporator through refrigerant piping and compresses it to a higher pressure. Compression also results in a higher temperature of the refrigerant. Compressors are usually centrally located in a machine room. There are three main types in use: piston, screw or turbo compressors.

- **Condenser:** Typically located separately, the heat exchanger transfers the heat from the refrigerant to the ambient air. High-pressure refrigerant gas from the compressor is condensed into the liquid phase as it is cooled inside the condenser at about constant pressure. A high-pressure, medium-temperature liquid refrigerant is then leaving the condenser.

- **Expansion Valve:** It releases the high-pressure liquid in a controlled fashion. When the refrigerant is depressurized, the boiling point of the refrigerant is reduced. The refrigerant is than evaporating at low temperatures, taking up the heat to provide the cooling.

Refrigerants

Refrigerant should fulfill a number of requirements.

- For efficiency reasons they should have a high enthalpy of evaporation and a dew and boiling point at a pressure that is technical feasible to achieve.
- For applicability reason they should have a high chemical stability
- For security reasons they should not be flammable, explosive or toxic.
- For environmental reasons it should have a low ozone layer depletion potential and a low global warming potential.

The main groups of refrigerants are Ammonia and halogenated hydrocarbons. Chlorofluorocarbons (CFC) such as R-12, hydro chlorofluorocarbons (HCFC) such as R-22 and hydro fluorocarbons (HFC) such as R-134a, R-404 or R-507.

In the past CFC were commonly used as refrigerants, but have been phased out due to international agreements due to their ozon depletion potential. The use of HCFC such as R-22 in new installations has been forbidden since 2000.

Further alternatives for hydro chlorofluorocarbons are natural refrigerants such as carbon dioxide, ammonia or water. Typical refrigerants of today are:

Ammonia NH_3 (R-717)

Ammonia is used as refrigerant in large industrial plants. Both the liquid and gas phase are colorless. It has an extremely pungent and offensive odor. Ammonia burns when heated and may be explosive at high temperatures. Ammonia in the gaseous phase is about half as heavy as air. The main disadvantage of Ammonia are the higher requirements on safety.

R-134a

R134a is a single hydro fluorocarbon or HFC compound. No chlorine content, no ozone depletion potential and has a modest global warming potential. Applications are in the automotive sector, stationary A/C and medium temperature refrigeration

R407C

R407C is a ternary blend of hydrofluorocarbons or HFC compounds containing 23% of R32, 25% of R125 and 52% of R134a. R407C has been established as a drop-in alternative for R22 in the industry. However, when a system is charged with a zeotropic mixture, it raises concerns about temperature glide at two-phase state and differential oil solubility.

R123 Dichlorotrifluoroethane $CHCl_2CF_3$

is a synthetic, non-combustible, volatile liquid that is mainly used as a refrigerant in commercial and industrial air-conditioning installations. R123 is currently used as a transitional replacement for chlorofluorocarbons and bromofluorocarbons phased out pursuant to the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. The 1992 Copenhagen Amendment to the Montreal Protocol requires that R123 and other hydrochlorofluorocarbons be phased out by 2020.

R22 Chlorodifluoromethane $CHClF_2$

R22 is a single hydro chlorofluorocarbon or HCFC compound. Low chlorine content and ozone depletion potential and only a modest global warming potential. R22 can still be used in small heat pump systems, but new systems can not be manufactured for use in the EU after 2003. From 2010 only recycled or saved stocks of R22 can be used. It will no longer be manufactured.

Little odor, colorless as gas or liquid, non toxic, non irritating, non flammable, non corrosive, stable

Applications: Packaged air-conditioning units where size of equipment and economy are important. Air Conditioning, Low and Medium Temperature Refrigeration

The following table gives an overview about the refrigerants used besides ammonia

Compressor	Typical capacity range	Drop in refrigerant alternatives
Reciprocating	70 to 500 kW	HFC-407C
Screw	150 to 1500 kW	HFC-407C HFC-134a
Scroll	70 to 300 kW	HFC-407C HFC-134a
Centrifugal	Over 500 kW	HFC-134a HCFC-123

B. Documentation and measurement of system operating parameters

Documenting or measuring of the following elements is desirable for all systems, and essential for large systems (over 20 kW). Collection of this data could be carried out by qualified in house engineering staff, or by a third party, such as an MCP endorser.

1. Load / unload differential
2. Type and functioning of system control and individual refrigerant controls
3. Total power consumption (including fans on condenser)
4. For large systems, a data logger and appropriate input devices should be used (probably installed for the assessment period only) to measure: pressure, temperature, flow, power/current and relative humidity.

C. Global indicators of system performance

On the basis of the data collected, the following global indicators of system performance can be estimated.

1.Annualised Capital Cost [Euro/a]		A.Annual Operating hours [h/a]	
2.Annual Maintenance costs		B.Electric Power	

[Euro/a]		[kW]	
3.Energy costs [Euro/a]		C.Coefficient of performance(1) [-]	
4.Total Cost (Sum of 1-3) [Euro/a]		D.Cooling Power (B*C) [kW]	
Overall specific refrigeration costs (D/4) [Euro/kWcooling]			

(1) If unknown a good estimation of the COP can be made based on the temperatures in the condenser and the evaporator. $COP = 0.5 \cdot \frac{T_{evaporator}}{T_{condenser} - T_{evaporator}}$

(Please note that Temperatures are in Kelvin).

Note that for many systems (particularly smaller ones under 10 kW) the potential savings would not justify the complex and costly data collection necessary to establish precise figures. In such cases, the assessment could be based on appropriate rules of thumb, for instance:

- annualised capital costs might be estimated at 7% of current replacement cost of entire system;
- maintenance might be 4% to 5% of current replacement cost;
- energy costs might be estimated from nominal power and operating hours.

3. Assessment of the applicability of energy saving measures

The electricity consumption of refrigeration systems can be reduced by the following **general** measures.

System optimization – Industrial refrigeration processes have in general high efficiencies, main efficiency measures are therefore the optimal dimension and design of refrigeration demand and cold generation, especially in part load operation. These measures should also comprise the control of the overall system.

Operating and maintenance efficiency measures – Operating and maintenance practices can also significantly improve the efficiency of refrigeration systems. Cleaning cooling coils several times a year and make sure outdoor coils are shaded from the sun and have good air circulation around them. Make sure the doors on freezers and refrigerators seal tightly, and any damaged door seals are repaired. Saving potential is between 4 – 8 % if maintenance is done regularly.

The reduction of the cooling demand can be achieved by the following **detailed** measures:

- **Improved Drive Motors (saving in the range of up to 7 %)**
  - Use of high efficient motors (EFF1) to drive the refrigeration compressor

  - Use of high efficient motors (EFF1) to drive the refrigerant pumps
  - Use of high efficient motor (EFF1) to drive the fans on the condenser

- **Use of adjustable speed drives for part load operation (saving in the range of up to 50 %)**
  - Use of an adjustable speed drive to drive the refrigeration compressor
  - Use of an adjustable speed drive to drive the refrigerant pumps
  - Use of an adjustable speed drive to drive the fans on the condenser

- **Heat recovery –** The refrigeration compressor is producing waste heat. Together with the heat release from the refrigerant condenser this heat can be used for other purposes such as space heating or hot water generation. Availability of heat however depends on the operation of the system, producing more heat during summertime.

- **Evaporative condensers –** Most refrigeration systems use air-cooled condensers to expel heat. Evaporative condensers use a wetted filter to cool ambient air as it enters the condenser increasing its ability to reject heat.

- **Placement of condenser** - Place the condenser in a shady place where the heat can easily flow away.

- **Avoid unnecessary low temperatures** – Check which temperatures a required in your process. Try to keep the refrigerant temperature as high as possible.

- **Cleaning of heat exchangers –** Clean your heat exchangers on a regular basis. Proper heat echange surface will assure high heat transfer capabilities. Maintenance plays an important role for a high efficient refrigeration system.

- **Floating head pressure controls –** Floating head pressure controls allow compressor head pressures to vary with outdoor conditions. This saves energy dollars and helps refrigeration equipment to last longer. Floating head pressure controls are often standard features on new systems; however, they can be retrofitted as well.

- **Defrost controls –** Energy-efficient defrost systems improve the operation of the defrost cycle. The most effective controls are called demand controls which initiate defrosting in a variety of ways such as measuring the temperature or pressure drop across the evaporator, measuring frost accumulation and sensing humidity. All of these methods, if used properly, are more effective than using a simple timer clock to initiate defrosting. Energy savings estimates range from about 1 percent to 6 percent of refrigeration system energy use.

- **Refrigerant leakages** – Full performance is only obtained if the minimum refrigerant level in the system is maintained. Leakages of the refrigerant will not only harm the environment but will also decrease plant efficiency. Check therefore regularly the refrigerant level in your system.

- **Thicker Insulation –** Improvement of the insulation can reduce the heat losses and therefore reduces the cooling demand efficiently. Insulation should be foreseen on the equipment to be cooled as well as on the piping in which the refrigerant is flowing.
- **Energy-efficient lighting in cold storage –** All waste heat produced by other equipment in the cold storage needs to be compensated by the refrigeration system. The more efficient the equipment the lower the waste heat production is. If for example the lighting system is optimized by using T-8 fluorescent lamps and electronic ballasts the internal heat load and therefore the cooling load can be reduced. Even better is to switch of the lights when not needed.
- **Ice storage tanks** – Ice storage systems can be used to optimise the operation of the system. However due to the fact that the storage will have additional losses, the use of ice storage should be carefully evaluated under energetic and economic conditions.
- **Expansion turbine –** Instead of expanding the refrigerant in a throttle it would be possible to expand it in a small turbine to generate mechanical power from the pressure decrease of the refrigerant. However these types of systems are very expensive and could therefore be only economical for large refrigeration systems with high number of operating hours.
- **Absorption refrigeration systems** – In the case of waste heat the use of absorption refrigeration systems can improve the overall efficiency. They can use heat instead of electricity to drive the refrigeration process.

Of course, the applicability of particular measures, and the extent to which they might save money, depend upon the size and specific nature of your operation. Only an assessment of the system and of your company's needs can determine which measures are both applicable and profitable. This could be done by a qualified refrigeration service provider (who might be an MCP Endorser) or by qualified in-house engineering staff.

The assessment conclusions will identify the measures which are applicable to your system, and will include an estimate of the savings, the cost of the measure, as well as the payback time. Assessment results are confidential in house data, not reported to the Commission.

The following table shows the potentially significant energy savings measures which might be applicable to your system. In the table, the measures are presented beginning with those that have a large potential impact and are the easiest to implement.

Table 1: Refrigeration energy efficiency measures

Measure	Saving potential
Reduction of cooling demand	
System optimization	8 – 10 %
Operating and maintenance measures	4 – 8 %
Thicker Insulation	5 – 10 %
Heat recovery	
Efficient equipment/lighting in the cold storage	
Use of efficient equipment	
Adjustable speed drives for compressor, fan, pumps	4 – 6 %
High-efficiency evaporator fan motors	2 - 5 %
High-efficiency compressor systems	2 - 5 %
High-efficiency condenser fan motors	2 - 5 %
Evaporative condensers	
Proper operation avoiding unnecessary low temperatures	
Cleaning of heat exchangers	
Liquid pressure controls	
Floating head pressure controls	
Defrost controls	

The assessment should, for each of the measures evaluate applicability and profitability. This might take a form similar to the following table.

Refrigeration energy efficiency measures					
	Assessment results				
Energy saving measures	Specific proposed action	Estimated annual savings	Investment cost	Annual O&M cost	Estimated payback time (months)
Thicker Insulation					
Heat recovery					
Efficient equipment/lighting in the cold storage					
Adjustable speed drives for compressor, fan, pumps					
High-efficiency motors					
…					

4. Action Plan

Your company's Action Plan, as proposed in the form below, should indicate:

- the measures you have decided to implement, and the time scale for implementation;
- the reasons for excluding the other measures.

The Action Plan is presented to the Commission. After approval, your organisation will be recognised as an MCP Partner.
Fill in for each refrigeration system

Refrigeration energy efficiency measures	Feasibility (1)	Specific Actions (2)	% Covered (3)	Time table (4)	Expected savings (5) (MWh/year)
Thicker Insulation					
Heat recovery					
Efficient equipment/lighting in the cold storage					
Adjustable speed drives for compressor, fan, pumps					
High-efficiency motors					
…					

Legend:
(1) **Feasibility.** Indicate obstacles to application by one or more of the following codes:
NA Not applicable for technical reasons
NP Not profitable
NC Not considered, because evaluation would be too expensive
If this field is left blank, the measure is considered to be both applicable and profitable.
(2) **Specific Actions.** Several specific actions may be adopted to implement one energy saving measure. For instance, buying a leak detector, and replacing low quality quick disconnects might be actions corresponding to the "Reduce air leaks" measure.
(3) **% Covered.** If the Partner's proposed commitment covers several refrigeration systems, this column should be used to indicate the proportion of the systems for which the specific actions will be implemented. This can be evaluated according to the most convenient indicator: number of systems; power; energy consumption. Specify the indicator used, as by: "%"; "%kW", %kWh"
(4) **Time table.** The time scale at which the action will be implemented. This might be a specific period or date, or might depend on some other action, for instance "When refrigeration is replaced", or "When paint shop is refurbished".
(5) **Expected savings** in MWh/year. This will often be an estimate, based on generally accepted practice.

5. Annual Report

The Annual Report to the Commission specifies progress made in carrying out the Action Plan, and will comment on any new or amended initiatives. The following reporting form should be used with progressive updating on an annual basis. The two left hand columns are copied from the Partner's Action Plan as approved by the Commission.

Refrigeration energy efficiency measures		
Approved Action Plan		Annual report for year 20xx
Actions decided upon to implement energy savings measures	Agreed upon time scale for action	Progress on action, as percentage achieved, and comments where appropriate (1)
Action 1		
Action 2		

(1) The percentage achieved could refer to an indicator such as the proportion of systems in the scope of the Action Plan for which the specific action has been completed.

Partners may find it useful to produce parts of the following Synthesis of the results of commitment to the Challenge. They are invited (but not required) to submit the Synthesis to the Commission.

Annual report synthesis		
	Since commitment	This year
Percentage of actions in Action Plan completed		
Estimated total investment for Plan (000 EUR) (1)		
Estimated change in non energy O&M costs (000 EUR) (1)		
Estimated energy savings (MWh) (2)		

(1) Investment and O&M costs are estimates of changes in costs, with respect to what would have been spent without Partner commitment to the Challenge. This may be, for instance, additional investment for higher performance equipment, or increase/decrease in maintenance costs.
(2) Energy savings are generally difficult to measure precisely. They will usually be calculated using pro-rata estimates based on the assessment results and on generally accepted industry technical coefficients.