FACTORS AFFECTING ENERGY EFFICIENCY IN RADIATORS (DRY COOLERS) USED IN POWER PLANTS

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ABSTRACT

Increasing efficiency and reaching maximum power capacity output with minimized expenses is a very important point in our era for energy manufacturers. That point affects design of radiators (dry coolers) widely used in power plants for heat rejection from the system and urges manufacturers to develop high performance, energy-efficient, environment friendly, economic, and long life radiators. This paper is intended to provide information on the factors that affects energy efficiency of radiators.

1. INTRODUCTION

The required data for the design and selection of radiators used in power plants include the desired cooling capacity, the dry and wet thermometer temperatures of the ambient air, fluid (glycol/water) input and output temperatures, the percentage of glycol, water flow, the desired values for the water side pressure loss and the desired unit size. In addition to these data, the isolation, heat resistance and protection class properties and sound level limits are important as well.[1]

By knowing the design data specified above and the additional optional features, manufacturing firms may design and manufacture radiators in line with their own manufacturing techniques. It is highly important for potential difficulties which would not be easily remedied; that the manufacturing firms possess a performance approved design software and design the batteries by the help of this software/program. [2]

There are essential design data and criteria which need to be observed for achieving the desired performance in a radiator. These data and criteria have been explained below.

2. DESIGN DATA PERTAINING TO AND FACTORS AFFECTING THE PERFORMANCE OF RADIATORS

2.1 Ambient Conditions

The cooling capacity of a radiator can only be determined by knowing the conditions of its operating region. The most important criterion regarding the environment is the air inlet temperature. For example, the cooling capacities for various air inlet temperatures for a HT (*Jacket Water*) refrigerating radiator operating at 99ºC / 73ºC and for a LT (*After Cooler*) refrigerating radiator operating at 44ºC / 39ºC have been given in the following chart.

An important point to be considered for radiator selection is the necessity to know the cooling capacity of the Dry Cooler to be purchased in the conditions of the area in which it will be operated. In the current example, the HT Dry Cooler purchased according to its cooling capacity for an air inlet temperature of 25 ºC, yields 83% of the required capacity when operated in its actual operating area with an air inlet temperature of 35 ºC, this percentage is a only 37% for a LT radiator. [2]

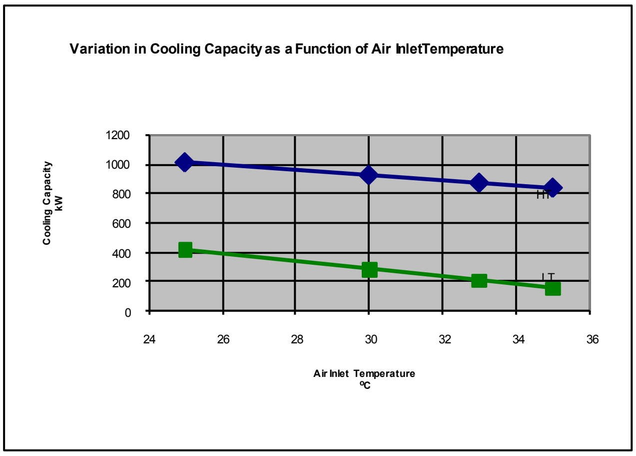


Chart 1. Variation in cooling capacity as a function of air inlet temperature [2]

2.2 Coolant Properties and Freeze Protection in Radiators

Another important design concern is whether the water circulating in the radiator circuit will be exposed to below zero outdoor temperatures. While 100% water may be used to meet the coolant requirement of the system, for operation in outdoor temperatures of below zero, a glycol-water mixture (brine) must be used to prevent freezing. For example, a mixture containing 20% ethylene glycol mixture by volume and a mixture containing 30% ethylene glycol by volume provide protection up to –8 °C and -16 °C respectively (See Table 1) [3].

The percentage of glycol to be added to the cooling water must also be taken into consideration for the design and selection of radiators. It must also be kept in mind that the capacity of the glycol-water mixture used in the cooling battery to prevent freezing is much lower than that in systems using 100% water, and consequently a larger heat transfer area, thus a larger (more costly) cooling radiator is required. Otherwise, the decrease in cooling capacity caused by the glycol which is added to water will cause the performance of the radiator to fall below expectations. Therefore, the value of the cooling capacity of the dry cooler is not meaningful in the absence of the design conditions and glycol-water ratio.

Capacity standards for radiators are defined for a 34% ethylene glycol mixture by volume, according to the TS EN 1048 standard (Heat Exchangers-Air Cooled Liquid Coolers "Dry Coolers"-Test Methods For Establishing the Performance).

Table 1 shows freezing points of mixtures by antifreeze volume [3]. The point which should be considered here is that freezing temperatures begin to increase when the glycol ratio exceeds 60%.

Table 1. Freezing Points of Mixtures by Antifreeze Volume [3].

Ratio of Mixture by Volume	Freezing Temperature
100% Water	0 °C
90 % Water + 10 % Glycol Mixture	-3 °C
80 % Water + 20 % Glycol Mixture	-8 °C
70 % Water + 30 % Glycol Mixture	-16 °C
60 % Water + 40 % Glycol Mixture	-25 °C
50 % Water + 50 % Glycol Mixture	-37 °C
40 % Water + 60 % Glycol Mixture	-50 °C
30 % Water + 70 % Glycol Mixture	*<-50 °C*
20 % Water + 80 % Glycol Mixture	*-45 °C*
10 % Water + 90 % Glycol Mixture	*-28 °C*

If precautions are not taken against the risk of freezing for dry coolers in winter months, the damages caused in pipes by the freezing of the internal coolant are almost inevitable (Even in instances where repair is possible, the additional cost will be accompanied by a performance drop in the dry cooler). In our country, the instances where dry coolers became unusable by freezing require complete replacement are quite common. Figure 1 shows the typical damage in the pipes of the dry cooler as a result of freezing [1].

Figure 1. Typical damage in Radiator pipes as a result of freezing [1].

The commonly used precaution against the risk of freezing is purging the water inside the Radiator in cold weather conditions when the system is not operated. Still, it is not possible to completely flush the water inside the Radiator, due to the piping structure, antifreeze (ethylene glycol) must be added to the cooling fluid in an adequate percentage. This precaution is also required to avoid freezing which may take place due to the unplanned energy blackouts that are quite frequent in our country.

2.3 The Fin Geometry

In radiator design, fin geometry which defines the diameter of the pipe and distances between pipes influences capacity and pressure losses. The fin geometry is selected among its own standards by the manufacturer so as to provide the required cooling capacity within the appropriate pressure losses.

Geometries with intensive piping can be said to yield more advantageous capacity/price ratios; however in this case, optimization is required since pressure losses will increase in tandem. Under practically, it should be considered that radiators having the same heat transfer surface, yet different geometries will yield different cooling capacities and pressure losses under the same conditions.

2.4 Air Velocity

Air velocity is an important criterion, since it affects the partial heat transfer coefficient on the air side. Since heat transfer increases with air speed, a smaller heat exchanger will be enough; however, in high speeds, the fan performance drops due to increased pressure loss in the air side. For this reason, air velocity must be selected at optimal values. The recommended air velocity in radiator applications is around 3-3.5 m/s. Air velocities below this figure require a larger radiator. Higher air velocities, on the other hand require stronger and costlier fans.

2.5 Standards and Energy Classification in Dry Coolers

Capacity standards for dry coolers are defined for a 34% ethylene glycol mixture by volume, according to the TS EN 1048 standard (Heat Exchangers-Air Cooled Liquid Coolers "Dry Coolers"-Test Procedure For Establishing the Performance) [4].

Cooling batteries must be manufactured in conformance to the SEP (Sound Engineering Practice) defined under 97/23/EC PED (Pressure Equipment Directive) and the entire unit must meet CE requirements [5].

Energy efficiency in products may be calculated for the value ranges given in Table 2, as per the EUROVENT Rating Standard (For Forced Convection Air Cooled Liquid Coolers "Dry Coolers") 7/C/003 – 2007 [6].

Table 2. Energy Efficiency Class

Class	**Energy Consumption**	**Energy Ratio (R)***
A	Extremely low	R > =110
B	Very low	70 =< R < 110
C	Low	45 =< R < 70
D	Medium	30 =< R < 45
E	High	R < 30

** The energy ratio "R" is obtained by dividing the standard capacity of the product by the total energy consumption of fan motors.*

There is a significant correlation between increasing energy efficiency and initial investment costs. While the initial investment costs of products with high energy efficiency is relatively high, they can be said to make up for the difference in costs in a short while.

Table 3 shows a sample comparison between two radiators assumed to have the same operating conditions and equal capacities. For the comparison, the cooling requirement of the system per radiator has been assumed to be 1400 kW and alternative radiator designs have been made accordingly. The basic differences between sample units are heat transfer surfaces, unit sizes, surface air velocities, electrical powers, energy efficiency classes and costs. The unit with a higher initial investment cost has a larger size and heat transfer area. This has a direct bearing on cost. However, low values for the air velocity and consequently for pressure loss on the air side has an impact on the electricity consumption value, which lowers costs of consumption. This increases the energy efficiency of the unit and elevates the unit from Class C to Class B as seen in the example. Table 4 shows the differences.

SPECIFICATIONS	**RADIATOR 1**		**RADIATOR 2**	
Q (Cooling Capacity)	1401	KW	1403	KW
Heat Transfer Surface	2705	m^2	3373	m^2
Coil Length	8500	mm	10675	mm
Air Velocity	3,67	m/s	2,72	m/s
Fan Diameter	1250	mm	1250	mm
Fan Rotation	750	d/d	750	d/d
Number of Fans	5		5	
Electrical Power of Fan	5,94	kw/h	3,61	kw/h
Total Electrical Power of Fan	*29.7*	kw/h	*18,05*	kw/h
*Energy Ratio (R)**	*47*		*78*	
Energy Efficiency Class	*C*		*B*	
Unit Price	*23300*	*Euros*	*25500*	*Euros*

Table 3. Sample comparison of the two assumed radiators [1, [2]

CALCULATIONS	**DIFFERENCES**	
Difference in the Total Electrical Power of Fan	11,65	kw/h
Difference in Annual Electrical Power of Fan	100656	kw
Cost of Electricity	0,08	$/kW
Difference in Annual Total Electricity Consumption	8052,5	$
Difference in Annual Total Electricity Consumption	5195,1	€
Difference in Monthly Total Electricity Consumption	432,93	€
Difference in unit costs	2200	€
Payback period	*5*	*months*

Table 4. Comparison of the assumed radiators and the calculation of the payback period of the initial investment cost. [1, [2]

2.6 LT-HT Radiator Design

A special system which offers advantages in terms of cost and occupied space can be employed for the heat rejection of motors used in power plants. In the HT (Jacket Water) circuit, the average temperature of the circulating water is high. On the other hand, water at lower temperatures circulates in the LT (After Cooler) circuit. Even after the air used to refrigerate the LT circuit warms up, its temperature remains sufficiently low to meet the cooling demand in the HT circuit. For this reason, instead of using a new radiator for the HT circuit, LT-HT radiators where two heat exchangers are cooled with the same fans can be utilized [7].

Figure 2. An LT-HT Radiator[1]

In LT-HT Radiators, the outlet air of the LT circuit is the inlet air of the HT circuit. The air entering the LT circuit in room temperature becomes somewhat warmer while cooling the After Cooler water. Since it is this warmed air which will enter the HT circuit, a larger heat transfer surface is needed than the one used for cooling with ambient air, to provide the cooling requirement for the Jacket Water. On the other hand, the initial investment advantage of solving the system within the same casing should be considered [7].

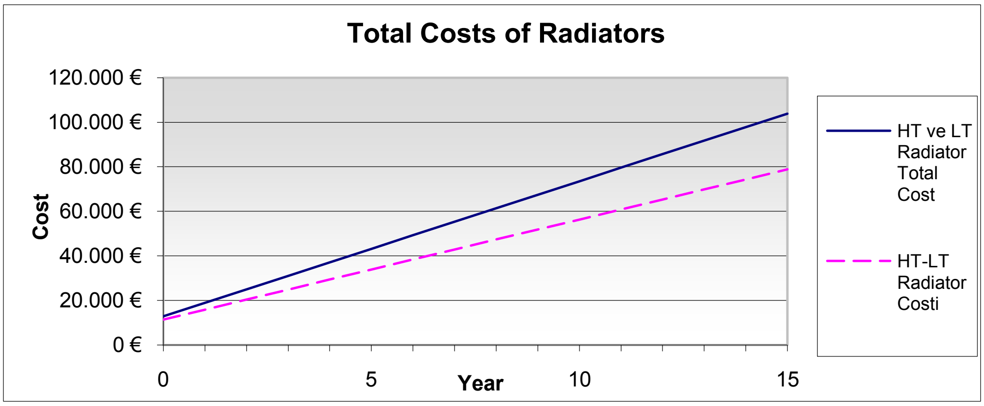


Chart 2. Variation in total cost (initial investment +operational) in years in cases where HT and LT radiators are built separately or in conjunction (the LT-HT Radiator) [7]

2.7 Noise Level and Fans

Particularly in applications near residential areas, low noise levels for the operation of dry coolers becomes an important criterion. The noise level which results primarily from the fan motor and the design of the fan blades is determined by evaluating manufacturer's data and checked in terms of conformance to the prescribed specifications. The sound level may be reduced by decreasing motor rotation, if need be; in this case the heat transfer area of the heat exchanger should be increased in order to provide the required cooling capacity.

Another point which requires consideration in radiator selection is the necessity to assure the adequacy of the design to provide the cooling capacity required in conditions of high ambient temperature. In periods where air temperatures are low, operating all fans at maximum rotation to achieve the desired capacity will be superfluous and costly. In systems monitored by cooling water outlet temperature, operating fans at low rotation or disabling them will provide an air supply of sufficient flow to the system.

2.7.1 Two Speed Fans

The most practical means of supplying air of varying flow is to use a two speed fan. Thanks to these fans that can operate at a secondary speed like 3/4ths of the highest operating rotation, a substantial amount of energy can be saved in periods where the air inlet temperature falls far below design temperatures.

For example an 870 kW dry cooler with four fans may be operated with lowered fan rotation when ambient temperature drops from 33 ºC to 20 ºC. In this case, 0.75 kW less of power will be consumed per fan, which means an energy consumption of nearly 40 %. This example pertains to 4 fans, systems of a much higher number of fans are being operated in most plants.

The power consumed by the 800 mm diameter fan in both speed and data belonging to another fan which may be used in lower rotations has been given below [8].

880 d/d	2.00 kW
660 d/d	1.25 kW
440 d/d	0.37 kW
330 d/d	0.20 kW

2.7.2 Use of Frequency Inverters and Step Control Units

With control units used both in single and two speed fans, air flows can be adjusted to needs.

In places where sensitive control over fan speed is not required, step control systems where fans are sequentially enabled and disabled are implemented. The working sequence of fans can be determined by the users, and alternatives where fan operating periods are evenly distributed are also available. Since step control units operate on the basis of the fans being enabled or disabled, they can be manufactured at a lower cost than systems monitoring fan rotation. For this reason, this method is widely preferred for systems including a great number of fans and which do not require sensitive control.

The chart below shows the amount of energy saved in a step controlled operation of a dry cooler with 4 fans. It has been assumed that all 4 fans operate at the hottest hours of the day and that a single fan is sufficient at the coolest hours.

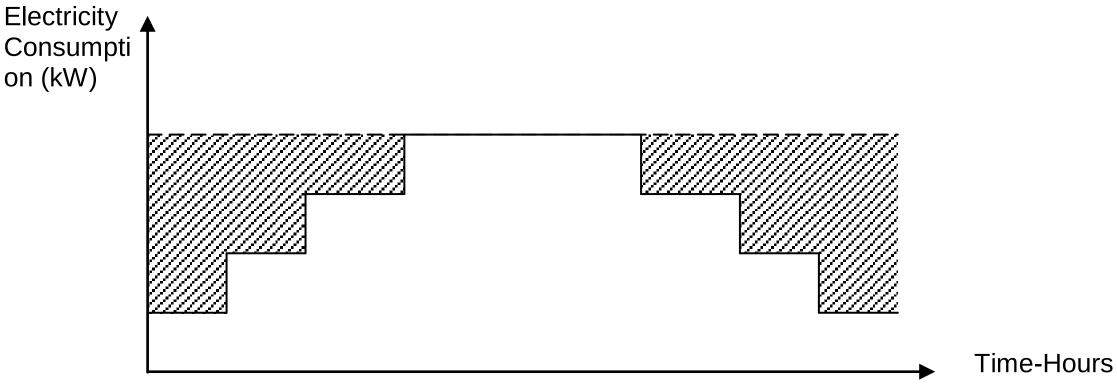


Chart 3. Electricity consumption of fans over a period of one day, in a dry cooler where fans are enabled according to need by way of step control. (The filled area indicates the amount of electricity consumed by not using all fans simultaneously, in terms of kWh

In places where the cooling water return temperature is desired to be low and where the number of fans used are low, step control will not yield adequate results. In such cases, systems monitoring fan speed and which therefore offer much more sensitive control over air flow (frequency inverters/converters) are used. Frequency inverters/converters are more expensive than step control unit in terms of initial investment cost; therefore the systems that are widely preferred are those where fans are controlled in groups and step control units and frequency inverters/converters are used together, as opposed to systems where all fans are controlled by separate frequency inverters/converters.

2.7.3 EC Fans

In addition to motor options of various speed ranges, the EC Motor technology whose areas of use have increased significantly over the last few years, can be used with up to Ø 1000 mm diameter fans in dry cooling applications. For fans of larger diameter, Frequency inverters are used. EC fans facilitate controlling the fan motor at all speeds, independently of the number of poles. As seen in

Chart 4.A, EC Motor systems save an average of 10 % energy at nominal speed as compared to conventional speed control systems such as frequency inverter-step control-transformer frequency [9].

Due to the acoustically advantageous design of EC Motors, neither the unwanted resonances of frequency converter systems, nor the buzzing of fan controlled systems are observed in EC Motors. Thus, lower noise levels are achieved in EC Motor systems. As shown in Chart 4.B, while EC motor systems offer a minimum of 4 dBA advantage with respect to phase controlled and frequency converter systems, in low fan speeds and air flows in particular, this difference becomes as high as 15~30dBA.

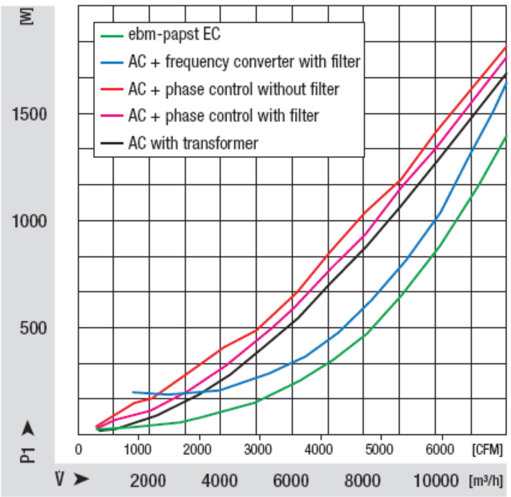


Chart4.A EC-Motor Power Consumption [9]

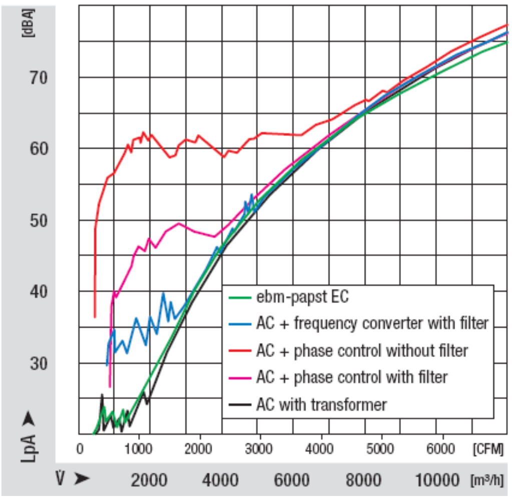
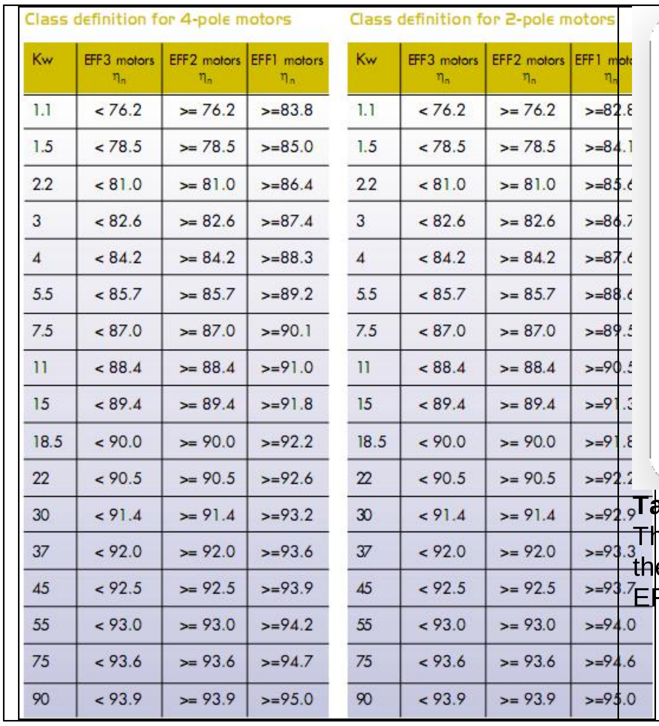


Chart 4.B EC Motor Noise Level [9]

2.7.4 High Efficiency Motor Utilization

The high energy efficiency of fan motors used in radiators affect the energy efficiency of the system as a whole, increasing efficiency. The energy efficiency levels of electrical motors are regulated as per the European Union directive on reducing CO2 emissions. The efficiency classification of 2 and 4 pole motors between 1.1-90 kW have been prepared by the European Committee of Manufacturers of Electrical Machinery and Power Electronics (CEMEP) in 1999. Three energy efficiency classes have been defined, which are: CEMEP EFF1, EFF2 and EFF3. Upon demand, “High Efficiency” motors in 6 pole motors and outside the 1.1-90 kW range can also be produced by manufacturing firms [10],[11].



Class definition for 4-pole motors

Kw	EFF3 motors η_n	EFF2 motors η_n	EFF1 motors η_n
1.1	< 76.2	>= 76.2	>=83.8
1.5	< 78.5	>= 78.5	>=85.0
2.2	< 81.0	>= 81.0	>=86.4
3	< 82.6	>= 82.6	>=87.4
4	< 84.2	>= 84.2	>=88.3
5.5	< 85.7	>= 85.7	>=89.2
7.5	< 87.0	>= 87.0	>=90.1
11	< 88.4	>= 88.4	>=91.0
15	< 89.4	>= 89.4	>=91.8
18.5	< 90.0	>= 90.0	>=92.2
22	< 90.5	>= 90.5	>=92.6
30	< 91.4	>= 91.4	>=93.2
37	< 92.0	>= 92.0	>=93.6
45	< 92.5	>= 92.5	>=93.9
55	< 93.0	>= 93.0	>=94.2
75	< 93.6	>= 93.6	>=94.7
90	< 93.9	>= 93.9	>=95.0

Class definition for 2-pole motors

Kw	EFF3 motors η_n	EFF2 motors η_n	EFF1 mot η_n
1.1	< 76.2	>= 76.2	>=82.8
1.5	< 78.5	>= 78.5	>=84.1
2.2	< 81.0	>= 81.0	>=85.6
3	< 82.6	>= 82.6	>=86.7
4	< 84.2	>= 84.2	>=87.6
5.5	< 85.7	>= 85.7	>=88.6
7.5	< 87.0	>= 87.0	>=89.5
11	< 88.4	>= 88.4	>=90.5
15	< 89.4	>= 89.4	>=91.3
18.5	< 90.0	>= 90.0	>=91.8
22	< 90.5	>= 90.5	>=92.2
30	< 91.4	>= 91.4	>=92.9
37	< 92.0	>= 92.0	>=93.3
45	< 92.5	>= 92.5	>=93.7
55	< 93.0	>= 93.0	>=94.0
75	< 93.6	>= 93.6	>=94.6
90	< 93.9	>= 93.9	>=95.0

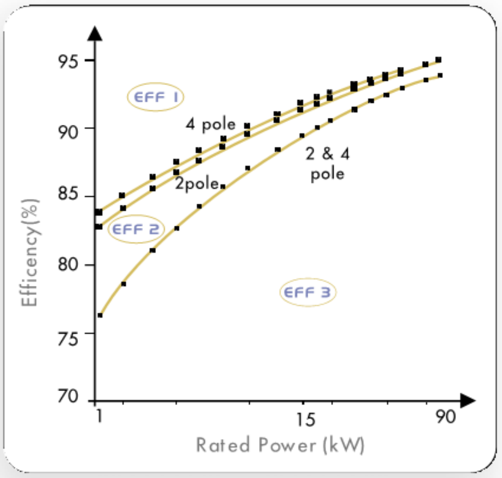


Table 5. and **Chart 5.**
The table on the left and the above chart indicate the efficiency comparison of EFF1, EFF2 and EFF3 classes for 2 and 4 pole motors [10].

For instance, energy losses in systems with high operating hours (6000 hours/year) decrease by 40 % by the use of class EFF1 high efficiency motors. (This percentage is approximately 20% for EEF2 motors.) A calculation for a 15 kW EEF1 class motor, will show the possibility of 4 MWh's of energy saving per year, which corresponds to 200 Euros annually at a rate of 0,05 Euro/kWh. It should also be borne in mind that high efficiency motors have a longer period of use and that they offer a short return on investment period [10].

3. CONCLUSIONS AND SUGGESTIONS

Increasing energy efficiency during the production, transmission and consumption of energy, in industrial enterprises, buildings, electricity generation plants, in transmission and distribution networks, and in air conditioning facilities as well as minimising the unit investment and operational costs have become the most important issue in today's competitive environment. This necessitates the design, manufacture and use of high performance and high efficiency Radiators which are inexpensive, durable, environment friendly.

Investors, project and application engineers operating within the energy sector, should be well versed in the issues described above. By the use of high energy efficiency products, the efficiency of our businesses will increase as well as our capacity for competitiveness. It should also be kept in mind that these systems are environment friendly as well.

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AUTHOR BIOGRAPHY

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