

FREE COOLING APPLICATIONS OF DRY COOLERS FOR AIR CONDITIONING AND PROCESS COOLING SYSTEMS

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ABSTRACT

The heightened emphasis placed today on energy efficiency in air conditioning and process cooling applications, has an impact on the design of cooling systems responsible for the majority of energy consumption in facilities; the tendency towards alternative systems in order to increase efficiency of natural resources is increasing and systems consuming less energy continue to be developed.

The system of free cooling which reduces operational costs with the increase in efficiency it creates, entirely or partially eliminates the need for operation of the cold water generating group at periods of low ambient temperature, thus saving substantial amounts of energy. Dry cooler systems have an important function in energy efficiency, operating with a cooling group or independently depending on properties of the application.

This paper will offer detailed and comparative information on "Dry Cooler Free Cooling Systems" which are among free cooling techniques categorised as "Free Cooling for Water-Side Applications" [1], emphasizing energy efficiency in cooling installations through sample applications in various sectors. Information will also be given on the material, performance and construction properties of dry coolers as well.

1. INTRODUCTION

Free Cooling Systems are grouped in two basic categories as applications in *Water-side* and *Air-side* systems. [1]

Free Cooling methods essentially categorized as free cooling for water-side cooling applications, include applications aiming to cut the cost of generating cold water from a central cooling group. Free cooling employed in systems requiring cooling water is obtaining cooling water without operating or partially operating the chiller compressor of the group by taking advantage of the low ambient temperature [1],[2].

Free Cooling applications for Water-Side Cooling Applications are further divided into two main categories.

- **Evaporative Cooling Applications**
 - Open Circuit Cooling Tower Applications
 - Closed Circuit Cooling Tower Applications
- **Heat Exchanger Cooling Applications**
 - Integrated Free Cooling Coil Applications
 - Dry Cooler and Wet/Dry Cooler Applications

While each system has its specific advantages and disadvantages, one of the main factors influencing the choice of system to be implemented, is the purpose to which the system is or will be used for. This has a direct bearing on the design of the system.

Another important factor is the climate conditions of the region in which the system will be installed. For the evaluation of possible advantages of free cooling applications while the cooling system is in the project development stage it is of utmost importance to know the frequency of occurrence throughout the year of temperature ranges in specific periods in seasons (Bin data) and to evaluate these data (the Bin method).

The issues listed below are other factors which need to be considered in system selection:

- The cooling capacity of the system
- The periods of operation and time of operation of the cooling group
- The cost of free cooling and the payback period with application
- The impact of the other auxiliary equipment on the system
- The cost of electricity, water, etc. of the region where the system will be installed

2. COOLING APPLICATIONS WITH HEAT EXCHANGERS

In air conditioning systems, various applications can be employed for the generation of cold water required in process water cooling facilities etc. Air / water cooled Chillers, open / closed water cooling towers, plate / shell and tube type exchangers are among these systems.

In addition to the mentioned applications, another type of system widely used in cold water generation is the dry cooler (finned block heat exchanger cooling coil) system. While these systems can operate without a cold water generating group depending on the required cold water temperatures, they can be used in integration or in connection with a cold water generation group for free cooling applications. These systems can be used as the ambient temperature drops 1.5 - 2.0°C below the required cooling water temperature.

The working structure of the system can be defines in three different approaches, which are:

1. Entirely mechanical cooling (No free cooling application)
2. Partial free cooling (Load sharing pre-cooling)
3. Entirely free cooling (the cooling group is not operational).

Thanks to closed circuit operation of this system, the problem of diminishing cooling water is not present; furthermore risks such as pollution, etc. are completely absent within the circuit.

The finned block heat exchanger cooling coil systems can be applied in two different forms:

1. Cooling Group and Integrated Free Cooling Coil Applications
2. Dry Cooler and Wet/Dry Cooler Applications

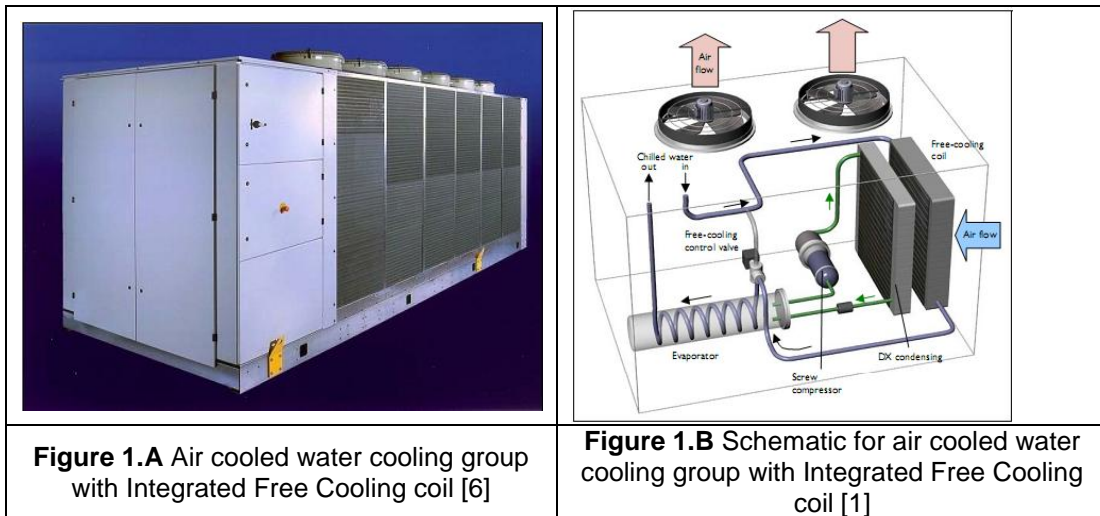
2.1 Cooling Group and Integrated Free Cooling Coil Applications

The greater emphasis placed on energy efficiency of installations has begun to influence the design of water cooling groups accounting for a significant share of the energy expenditure in plants. As opposed to conventional cooling groups, cooling coil groups with integrated free cooling coils have gained popularity of late. For example in Great Britain, the use of integrated free cooling coil water cooling groups have a significant role in the fact that 62% of the annual cooling demand is met through free cooling. In the country, only 38% of the annual cooling requirement is obtained from mechanical cooling [1], [4].

Groups with integrated free cooling coils are alternative systems for cooling applications used in large computer and server rooms, Internet and telecommunication data centers. They have the capacity for both mechanical and free cooling (partial and complete). [1]

Figure 1 A shows the cross section of the cased unit of the water cooling group with integrated free cooling coil, and Figure 1 B shows a simplified representation of the structure of this type of unit. The free cooling coil is placed in the front section –according to the air intake direction of the unit- of the air cooled condenser coil. As the ambient temperature drops below that of the return water, the control valve sends the return water to the free cooling coil for pre-cooling or for complete free cooling. [1]

The purpose for which the plant where the water cooling application will be used (air conditioning or industrial process cooling) must be specified for the design and selection of groups with integrated free cooling coils. Another important design concern is whether the water running in the 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 $-8\text{ }^{\circ}\text{C}$ and $-16\text{ }^{\circ}\text{C}$ respectively (See Table 4) [5]. There are two important points that should be kept in mind for the use of a glycol-water mixture system: The first point is 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 group is required. The second point is that the use of glycol-water mixture for air conditioning devices like central air conditioning units and fan coils is not desirable, since it would require an additional heat exchanger between the cold water unit designed for the glycol-water system and cold water circuit. The points mentioned above must certainly be considered prior to design, depending on the location and temperature of application.



The images below indicate the operating principle of integrated Free Cooling coil air cooled water cooling groups in Summer, Winter and Spring. The same basic approach is also employed in dry cooling systems, and the group and dry cooler operate as separate units.

Operating conditions for Summer:

The ambient temperature is above the desired cold water temperature and the return water temperature. (Example $T_{\text{ambient}}: 35^{\circ}\text{C}$, $T_{\text{cooling water}}: 10^{\circ}\text{C}$, $T_{\text{return water}}: 15^{\circ}\text{C}$). The cold water required is provided solely by the operation of the compressor of the cooling group within the conventional cooling cycle. The free cooling coil is not operational. (See: Figure 2.A1 – 2.A2).

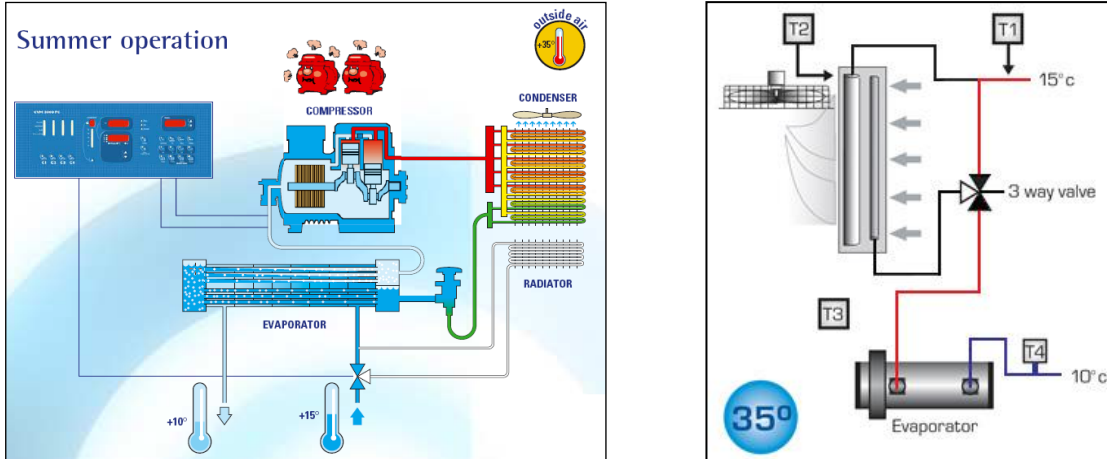


Figure 2.A1 – 2.A2 Operating conditions of integrated free cooling coil air cooling water cooling group for the Summer Season [7], [8]

Operating conditions for Spring:

The ambient temperature is above the desired cold water temperature and below the return water temperature. (Example $T_{\text{ambient}}: 13^{\circ}\text{C}$, $T_{\text{cooling water}}: 10^{\circ}\text{C}$, $T_{\text{return water}}: 15^{\circ}\text{C}$). The cooling water is first pre-cooled by ambient air by passing it through the free cooling coil. The free cooling capacity is dependent on the ambient temperature value. The three way valve and control unit make it possible to benefit from free cooling. (See: Figure 2.B1 – 2.B2).

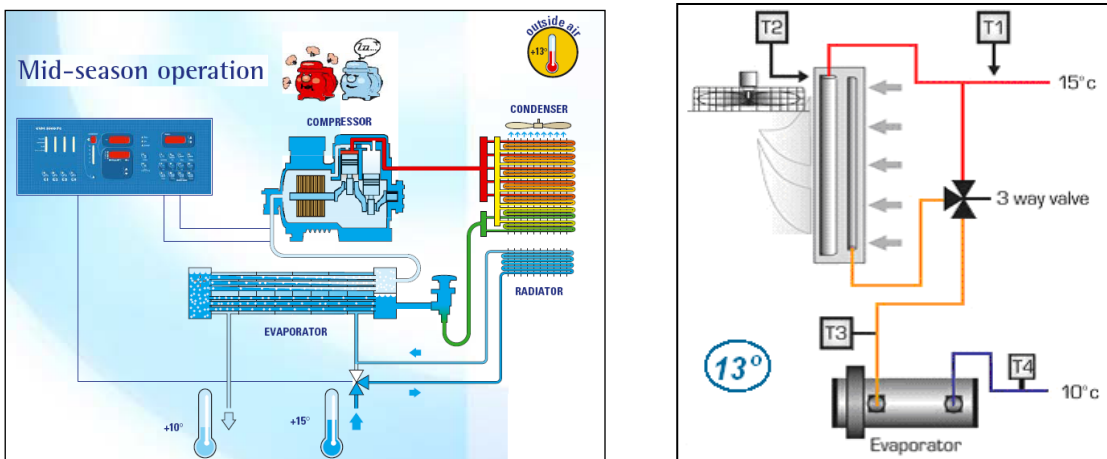


Figure 2.B1 – 2.B2 Operating conditions of integrated free cooling coil air cooling water cooling group for the Spring Season [7], [8]

Operating conditions for Winter:

The ambient temperature is below the desired cold water temperature and the return water temperature. (Example $T_{\text{ambient}}: 5^{\circ}\text{C}$, $T_{\text{cooling water}}: 10^{\circ}\text{C}$, $T_{\text{return water}}: 15^{\circ}\text{C}$). The cold water required in the system is provided entirely by the free cooling coil by virtue of the ambient air. In this case, the energy spent for cold water generation is limited to the amount drawn by the fans on the cooling group. (See: Figure 2.C1 – 2.C2).

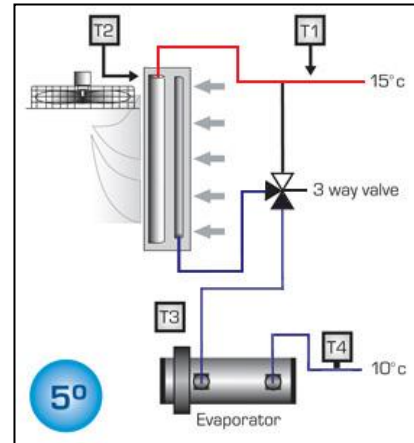
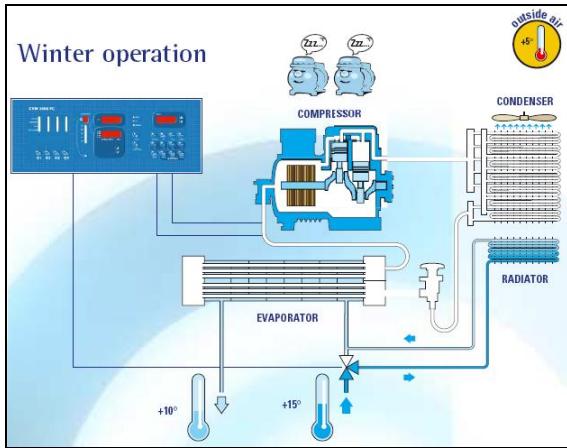


Figure 2.C1 – 2.C2 Operating conditions of integrated Free cooling coil air cooling water cooling group for the Winter Season [7], [8]

2.1.1 SAMPLE APPLICATION - 1: Integrated Free Cooling coil water cooling group application [9]

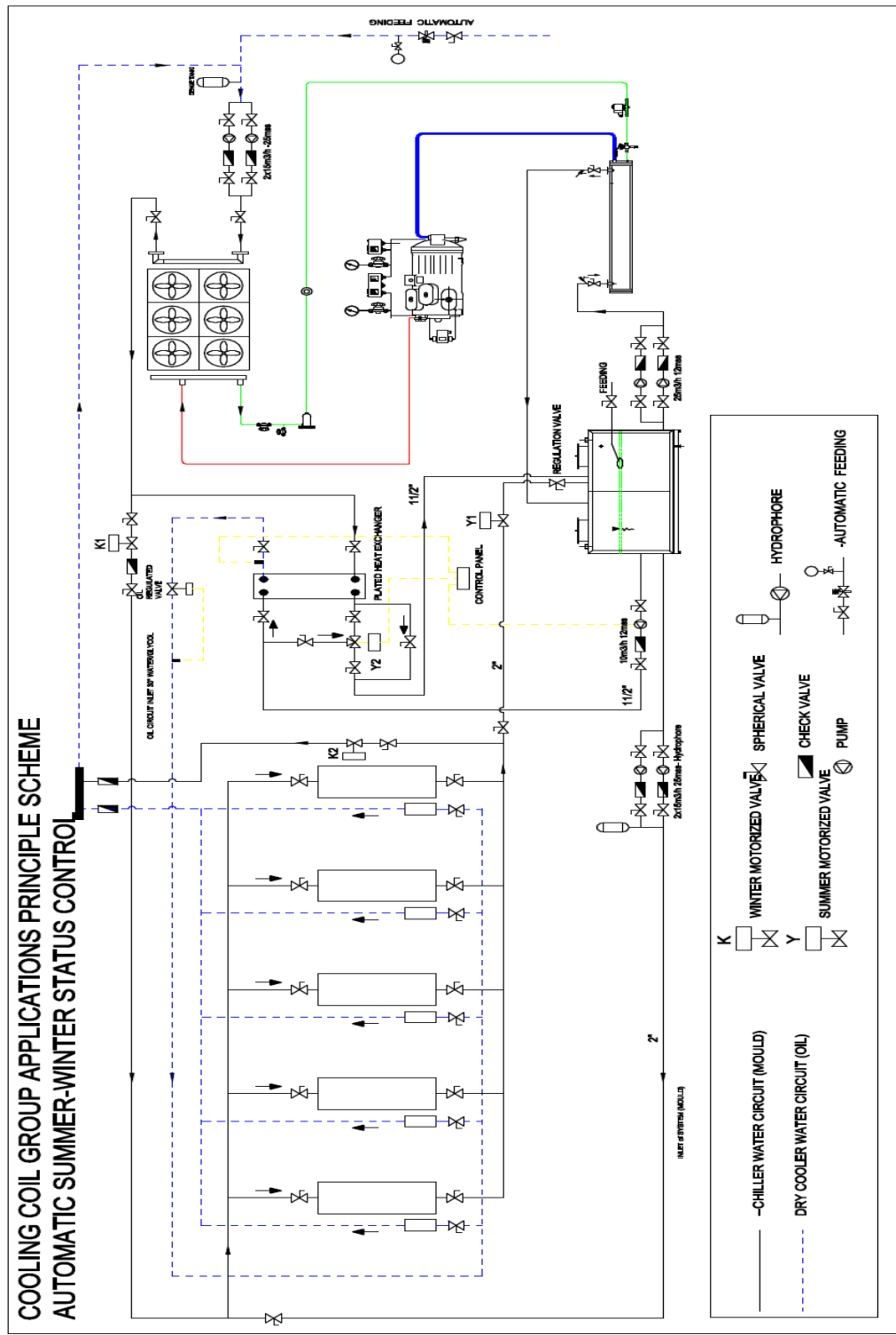


Figure 3. Principle scheme for the application of air cooled water cooling group with integrated free cooling coil [9]

The principle scheme in Figure 3 is of an application made in Istanbul in 2002 for the plastics sector. In the system, the cooling group is taken offline according to seasonal outdoor ambient temperatures, and free cooling is employed for mould and oil cooling. In this way, energy efficiency is achieved in the system. The operation is controlled with an automatic control system.

The free cooling coil is located –integrated– within the same casing as the condenser of the air cooled group. Thus, the unit has a compact structure.

The plant where the cooling system is installed operates in the plastics sector, manufacturing clothes hangers. (See: Figure 4).

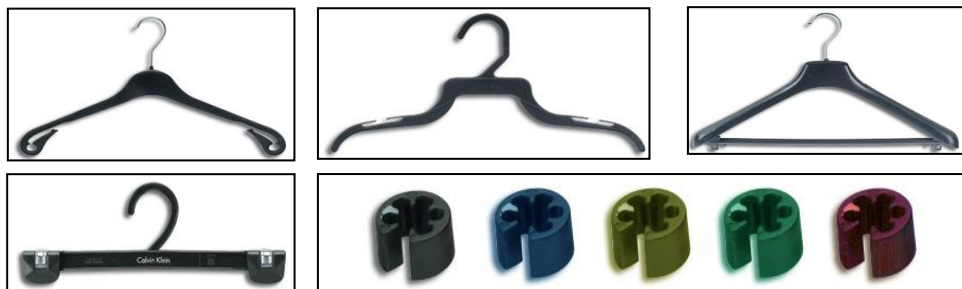


Figure 4. Samples of manufactured clothes hangers [10]

The factory carries on manufacturing for 12 months, 6 days/24 hours. A total of 7 injection machines work in connection with the air cooled water cooling group with integrated cooling coil whose principle scheme has been provided.

The system operates for 4 months (June-September) in the Summer position; and for 8 months (October-May) in the Winter position.

In the Summer Position (June – September)

1. To cool moulds: The cooler group is operated. Lower limit range for the operating temperature of cooling water: 24.5°C and the upper limit value is 26 °C. In the system the Chiller groups remains in standby for a total of 30 minutes and operates for the remaining 30 minutes of each hour. The material used in the manufacture of clothes hangers is polystyrene and polypropylene. Various trial runs made by the manufacturer have indicated that the cooling of the moulds at lower temperatures does not have a big influence on the manufacturing speed of the product (that it remains at a negligible level). Thus, moulds are cooled at relatively high temperatures. In case a different material is used for the product or product thickness increases, mould cooling water of lower temperature may be needed and the speed of manufacture may be increased by using water at lower temperatures.

2. For the cooling of hydraulic oils of injection machines_an integrated free cooling battery (integrated dry cooler unit) is used. Lower limit range for the operating temperature of oil cooling is 30°C, the upper limit value: 36 °C. The plate exchanger is enabled for conditions of extreme heat, exceeding seasonal norms.

In the Winter Position (October - May)

1. For the cooling of moulds an integrated free cooling coil (integrated dry cooler unit) is used. The chiller group is disabled. Lower limit range for the operating temperature of cooling water: 24.5°C and the upper limit value is 26 °C. Of the six fans constituting the unit, two are constantly operational, and the remaining four are operated by thermostat control. (Furthermore, the air current created as a result of south westerly winds in January and February cause the fans to spin, in which case fans operate for only 5 hours of the day, providing an opportunity for further energy saving. Due to the unpredictable nature of this occurrence, it has not been taken into consideration in the analysis conducted for the application.

2. For the cooling of hydraulic oils of injection machines an integrated free cooling coil (integrated dry cooler unit) is used. Lower limit range for the operating temperature of oil cooling is 24.5°C, the upper limit value is 26.5°C. Since oil temperature remains low in winter months, the oil temperature is kept at the desired level by adjusting the flow of water in the line leading to the machines.

The Cooling Process	January	February	March	April	May	June	July	August	September	October	November	December
THE CONDITION IN EFFECT												
Mould Cooling	Dry Cooler					Cooling Group (Chiller)				Dry Cooler		
Oil Cooling						Dry Cooler						
THE SCENARIO WHEN FREE COOLING IS NOT USED												
Mould Cooling	Cooling Group (Chiller) 1											
Oil Cooling	Cooling Group (Chiller) 2											

Table 1. Cases where the existing cooling system is operated and where free cooling is not used

In the calculation of the gain from free cooling, the existing condition of the system has been compared to the case where free cooling is not used (a secondary cooling group is used).

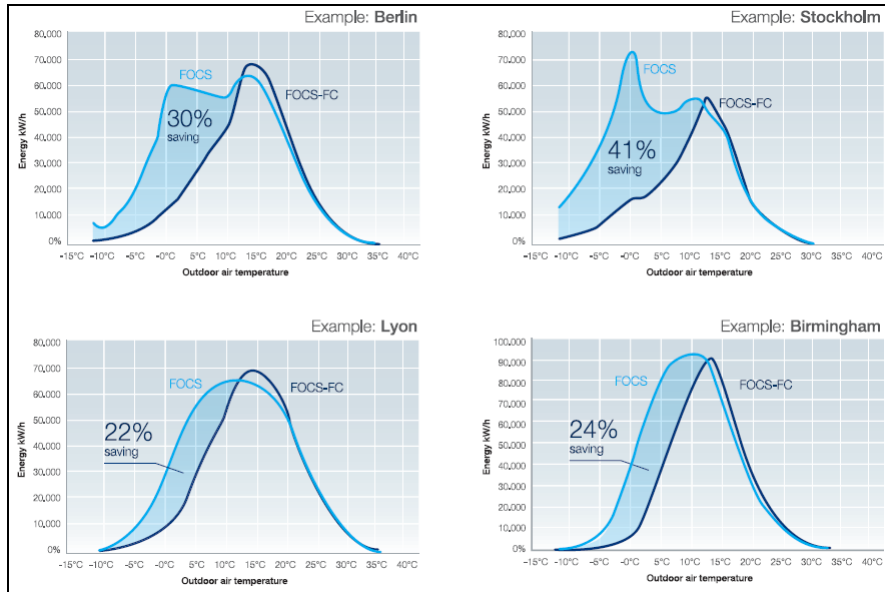
The cooling capacity needed in the system is 180 kw. In the existing state 60 kW and 120 kW of power are required for mould cooling and oil cooling respectively. Since a water cooling group of greater capacity than required was selected in order to accommodate further capacity requirements as they emerge within the scope of future investments, it remains on standby for a total of 30 minutes in an hour and operates for the remaining 30 minutes. The free cooling coil is located –integrated- within the same unit as the condenser of the air cooled group. The unit contains 6 high revolution Ø630 mm diameter fans.

For the scenario when free cooling is not used, the use of two 120 kW chillers was assumed to accommodate the 180 kW cooling capacity needed for the oil and mould cooling processes in the system. To make up for the 180 kW cooling load required by the system, the chillers of a total capacity of 240 kW need only operate 18 hours each. For the analysis the unit price of electricity was assumed as 0.09 €/kWh, VAT and other additions included. The energy expenditure during process cooling in Summer and Winter months with and without free cooling has been summarised in the table below with respect to periods and the economic gain has been indicated. The application in question offers a gain of €15,998.73 (63.72%).

THE EXISTING STATE (CHILLER + FREE COOLING COIL APPLICATION)		
MOULD COOLING & OIL COOLING	THE SUMMER PERIOD of 4 months	€ 5,612.52
	THE WINTER PERIOD of 8 months	€ 3,498.08
	ANNUAL CONSUMPTION	€ 9,110.60
THE CHILLER + CHILLER SCENARIO (NO FREE COOLING)		
MOULD COOLING & OIL COOLING	THE SUMMER PERIOD of 4 months	€ 10,761.14
	THE WINTER PERIOD of 8 months	€ 14,348.19
	ANNUAL CONSUMPTION	€ 25,109.33
ECONOMIC GAIN (EUROS/YEAR)		€ 15,998.73
ECONOMIC GAIN (%)		63.72%

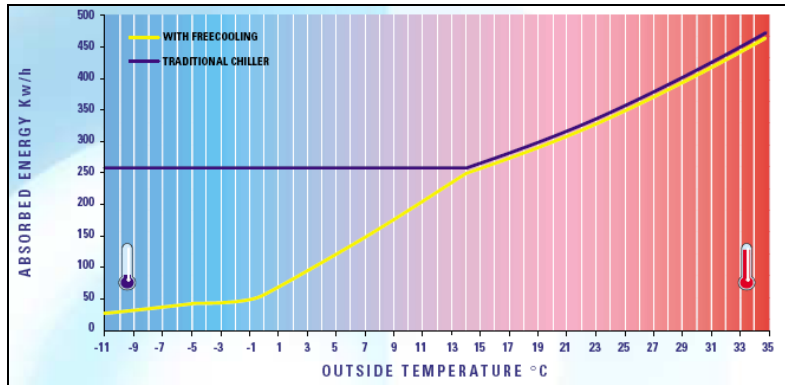
Table 2. Table showing gain from Free Cooling

In addition to the process cooling application, the conclusions related to measurements taken in four European cities by a chiller manufacturing firm on cooling groups with integrated free cooling coils in order to demonstrate the gain resulting from the use of Free Cooling in air conditioning systems have been given below in charts. (See: Graph 1).



Graph 1. Energy saving figures as a function of outdoor ambient temperature for groups with free cooling installed in air conditioning systems in four cities in Europe [11]

It is clearly apparent that the efficiency of free cooling increases for settlements in cold climates. The results from an integrated Free Cooling application for another air conditioning system of the manufacturer in Milan can be viewed from Graph 2. ($T_{\text{Outdoor ambient temperature}}: 30^{\circ}\text{C}$, $T_{\text{water going/returning}}: 10^{\circ}\text{C}/15^{\circ}\text{C}$, 30% Glycol mixture) The productivity gained in this example is 27.6% by the manufacturer's approach.



Graph 2. Free cooling comparison figures as a function of outdoor ambient temperature for the group with 1,123 kW cooling capacity installed in the air conditioning system in the city of Milan [11]

With respect to another theoretical study conducted for three cities in our country, the free cooling efficiency of a 1,625 kW cooling group has been calculated as approximately 15% for the conditions of İzmir, as approximately 30% for the conditions of İstanbul and as approximately 37% for the conditions of Ankara [12].

The following table shows the temperature figures over 11 years, issued by the Turkish State Meteorological Service. It is clearly evident that the benefits reaped from free cooling increase as the temperature of the required cooling water increases.

ISTANBUL	January	February	March	April	May	June	July	August	September	October	November	December
The Averages Values For Many Years Performed												
Average Temperature (°C)	6,1	5,9	7,7	12,1	16,7	21,5	23,8	23,5	20,0	15,6	11,2	8,0
Average Maximum Temperature(°C)	9,0	9,2	11,6	16,6	21,3	26,2	28,5	28,3	24,9	19,9	14,8	10,7
Average Minimum Temperature(°C)	3,6	3,2	4,6	8,3	12,4	16,8	19,4	19,5	16,0	12,3	8,3	5,4
Average Insolation Time (hours)	2,3	3,1	4,6	6,0	8,0	9,8	10,5	9,4	7,9	5,2	3,3	2,2
Average Number of Rainy Day	17,3	14,9	13,0	11,3	7,6	6,4	3,9	5,6	7,0	11,3	13,7	16,9
The Highest and Lowest Values For Many Years Performed												
Maximum Temperature (°C)	18,3	24,0	26,2	32,9	33,0	39,2	39,7	38,8	33,6	34,2	27,2	21,2
Minimum Temperature (°C)	-7,9	-8,0	-6,9	0,6	3,6	9,0	13,5	12,2	9,2	3,2	-1,0	-3,4

Table 3.A Temperature data over 11 years for İstanbul from the T.S.M.S. [13]

ANKARA	January	February	March	April	May	June	July	August	September	October	November	December
The Averages Values For Many Years Performed												
Average Temperature (°C)	0,4	1,9	6,0	11,2	15,9	19,9	23,4	22,9	18,5	12,9	6,6	2,3
Average Maximum Temperature(°C)	4,3	6,5	11,6	17,0	21,3	26,3	30,0	29,8	25,9	19,7	12,3	6,1
Average Minimum Temperature(°C)	-2,9	-2,2	0,8	5,7	12,4	12,9	16,0	15,8	11,7	7,3	2,2	-0,8
Average Insolation Time (hours)	2,6	4,0	5,6	6,4	8,0	10,4	11,4	10,9	9,4	6,6	4,4	2,4
Average Number of Rainy Day	11,5	10,2	10,2	12,6	7,6	9,3	4,0	3,3	3,7	7,3	9,0	11,1
The Highest and Lowest Values For Many Years Performed												
Maximum Temperature (°C)	16,6	19,9	25,7	30,3	33,0	37,0	40,8	39,0	35,2	32,2	24,4	18,0
Minimum Temperature (°C)	-21,2	-21,5	-19,2	-6,7	-1,6	5,0	6,8	7,2	2,8	-3,4	-8,8	-14,6

Table 3.B Temperature data over 11 years for Ankara from the T.S.M.S. [13]

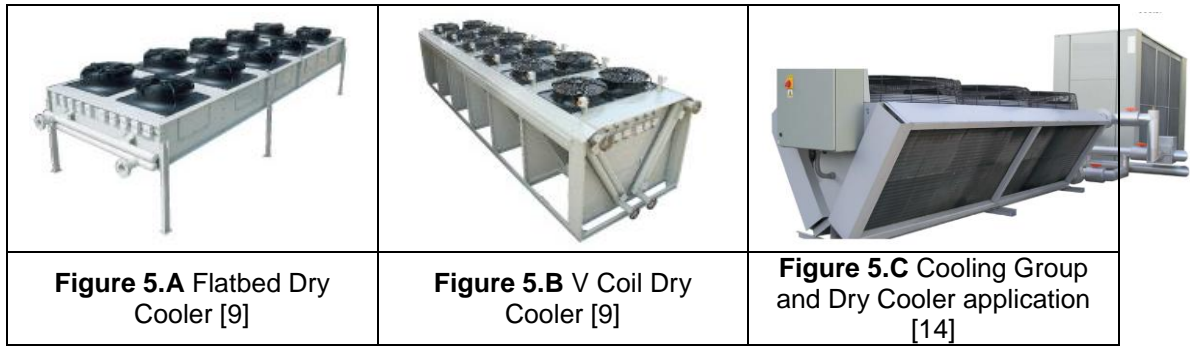
IZMIR	January	February	March	April	May	June	July	August	September	October	November	December
The Averages Values For Many Years Performed												
Average Temperature (°C)	8,9	9,1	11,7	15,9	20,8	25,7	28,1	27,4	23,6	18,9	13,7	10,3
Average Maximum Temperature(°C)	12,6	13,2	16,4	20,9	26,0	31,0	33,3	32,7	29,2	24,2	18,2	13,8
Average Minimum Temperature(°C)	5,9	5,8	7,7	11,4	25,6	20,1	22,7	22,4	18,7	14,7	10,4	7,5
Average Insolation Time (hours)	4,3	5,0	6,6	7,5	9,5	11,8	12,2	11,6	10,0	7,5	5,3	3,8
Average Number of Rainy Day	11,4	10,3	8,3	8,4	5,0	2,2	1,7	1,3	3,7	5,4	8,9	12,3
The Highest and Lowest Values For Many Years Performed												
Maximum Temperature (°C)	20,4	23,5	30,5	37,5	37,5	41,3	42,6	43,0	38,0	36,0	28,6	25,2
Minimum Temperature (°C)	-4,0	-5,0	-3,1	7,0	0,6	10,0	16,1	15,6	12,6	5,7	0,0	-2,7

Table 3.C Temperature data over 11 years for İzmir from the T.S.M.S. [13]

2.2 Dry Cooler and Wet/Dry Cooler Applications

2.2.1 Dry Coolers

Another finned block heat exchanger method used in water cooling is the system called Dry Cooler (Figure 5). They have a quite wide area of application in air conditioning and process water cooling systems. The basic principle is to transfer the return water load in the system to air by the aid of a heat exchanger system including fans. Its working principle is that the air sucked by fans cools the fluid within the block while it passes through the fins. In this method, the exterior surface of the exchanger is dry. In this case, problems such as scaling and corrosion do not exist. Thanks to closed circuit operation of the system, the problem of diminishing cooling water is not observed.



For dry coolers, the temperature of water generated depends on the dry bulb temperature of the environment, and this is why these units are called dry coolers. With dry coolers, water cooled to approximately 5 °C dry bulb temperature can be obtained. In cases where cooling water at lower temperatures is needed, Wet-Dry Coolers are used.

Dry coolers operate under the same principle as the previously explained free cooling coil systems. If a water cooling group has already been installed in the plant and if it is wished to take advantage of free cooling in low ambient temperatures, dry cooler systems will be ideal for this case.

While dry coolers in applications within the plastics, chemicals, energy, air-conditioning etc. sectors in tandem with a cooling group, they can also be used by themselves depending on cooling water temperatures. (See: Figure 5C, Figure 6 A,B,C).

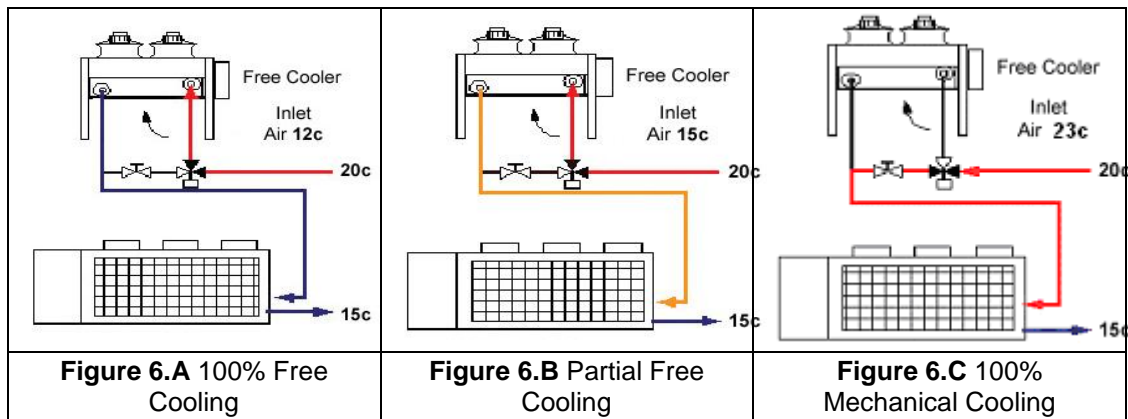


Figure 6.A, 6.B, 6.C Schematic representation of a dry cooler application with a cooling group [8]

Figure 7 show the principle scheme of a sample dry cooler system operating in load sharing with a package type air conditioning device. These are methods used in package type air conditioning devices used for computer and server rooms, Internet and telecommunication data centers which require around the clock cooling. The energy economy provided by the system during the night is quite substantial [1].

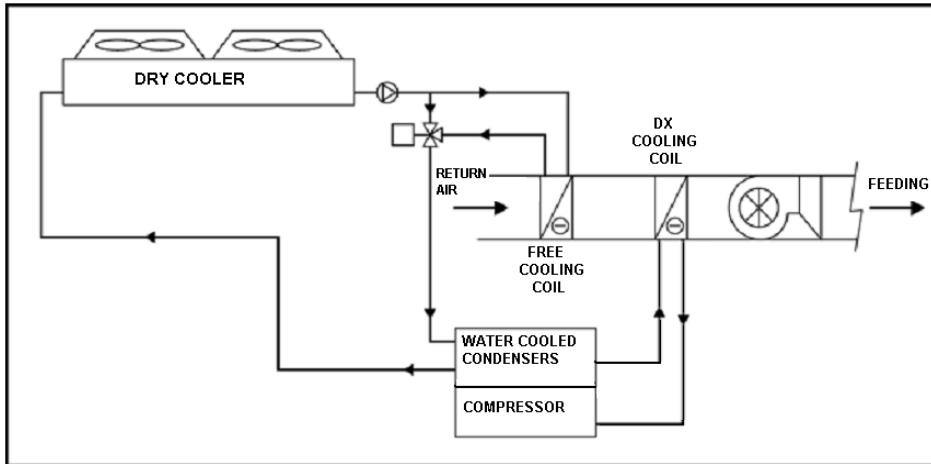


Figure 7. Principle scheme of the load sharing dry cooler system [1]

2.2.1.1 Freezing in Dry Coolers:

Measures should be taken against freezing in dry coolers for winter months. Otherwise, the damages caused in tubes by the freezing of the internal coolant will be almost irreparable (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 is quite common. Figure 8 shows the typical damage in the tubes of the dry cooler as a result of freezing [9].



Figure 8. Typical damage in dry cooler tubes as a result of freezing [9].

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

Table 4 shows freezing points of mixtures by antifreeze volume [20]. The point which should be considered here is that freezing temperatures begin to increase when the glycol ratio exceeds 60%.

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

The percentage of glycol to be added to the cooling water must also be taken into consideration for the design and selection of dry coolers. Otherwise, the decrease in cooling capacity caused by the glycol which is added to water will cause the performance of the dry cooler 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 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).

2.1.1.2 SAMPLE APPLICATION - 2: Dry Cooler application for Industrial Process Cooling [15]

Below is given information about the free cooling application used for cooling motors of print machines in a printing facility in İstanbul.

The specifications of water cooled motors of the manufacturing firm of the printing machine:

- Inlet / exit temperature of motor cooling water :27 °C / 35 °C
- Flow of water entering motors :13 m³/h
- Daily Hours of Operation :20:00-04:00 (365 days)
- Total cooling capacity :120 kW

The principle scheme of the cooling group developed to meet these requirements, in consideration of the fact that press machines will run at night has been given in Figure 9. The water leaving the motor cooler of the printing machines is initially sent to the dry cooler with the help of the water pump P1 and the water which is cooled in the dry cooler with cold air is then sent to the plate type heat exchanger. In the dry cooler operating according to the outdoor dry bulb temperature, in case the temperature of the cooled water exceeds 27 °C, the water is subjected to a secondary cooling process in the plate heat exchanger working in the 6/12 °C water regime.

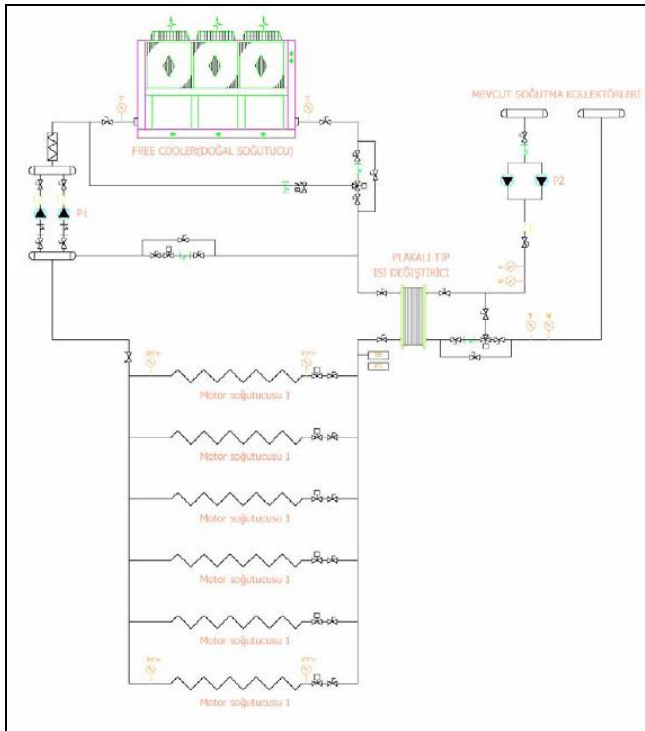


Figure 9. Motor Water Cooling System [15]

Glycol has been used in the water circuit in consideration of the possibility of the outdoor temperature dropping below 0 °C. 3 axial fans at 2 kW have been used to reduce the temperature of 13 m³/h water from 35 °C to 27 °C, in other words to accommodate the 121 kW heat load. The total power drawn by the fans has been measured as 3.9 kW. The COP of the system is ~ 30. In case this heat load is entirely accommodated by the air cooled cooling group, and if the COP value is taken as around 3, the spent energy is around $121/3 = 40$ kW. As a result the installed free cooling system has provided an energy economy of 90% and the system has self-financed in 5 months [15].

2.2.1.3 SAMPLE APPLICATION – 3 : Dry Cooler application for Industrial Process Cooling

The factory where the cooling system is installed operates in the automotive sector, manufacturing central and side consoles, ventilation panels, cup holders, ashtrays and other paraphernalia for automotive manufacturing firms like BMW, Honda, Ford and Volkswagen as a supply industry.



Figure 10. The dry cooler installed in the system [16]



Figure 11. Examples of manufactured products [17]

The dry coolers chilling the cooling water of production machines, are used in tandem with two 80 kW capacity cooling groups. The cooling groups are devices providing basic cooling in the system, and as

outdoor ambient temperature drops below 3°C, dry coolers come online in order to save energy and reduce noise levels. Glycol is used in the dry cooler system.

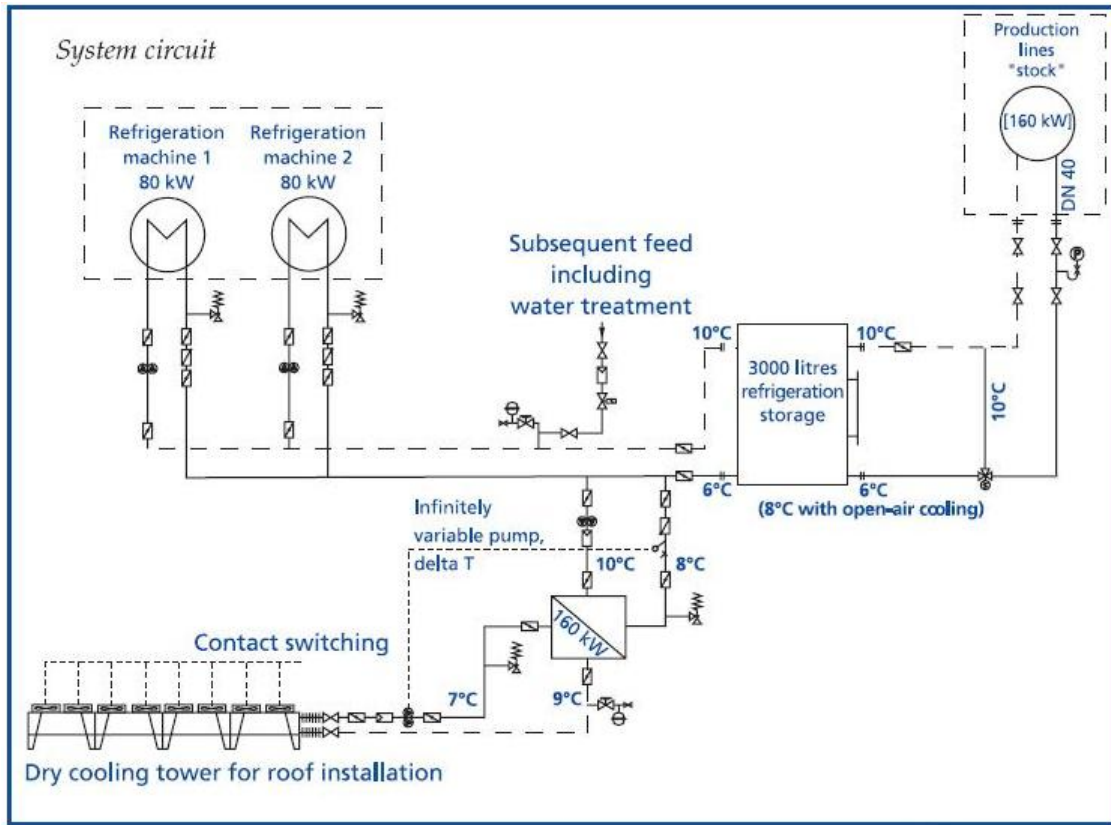


Figure 12. The principle scheme of the system [16]

Calculations have indicated that the free cooling provided by the use of dry coolers offers an annual energy savings of 33%. This saved energy has enabled the system to self-finance in approximately three years. The following tables show the gain from free cooling.

COLD PRODUCTION		
	100% compression	Open-air cooling in „winter“
Description	kWh/a	kWh/a
Compressor refrigeration	1,306	806
Open-air cooling		500
Total	1,306	1,306

COLD PRODUCTION		
	100% compression	Open-air cooling in „winter“
Description	DM/a	DM/a
Compressor refrigeration	103%	64%
Open-air cooling		6%
Total	103%	70%
→ Annual savings: 33%		

Table 5A - 5.B Tables showing the comparative gain from free cooling [16]

Dry coolers, in addition to being used as free coolers in industrial process water cooling system; they are used in the same capacity in air-conditioning systems. In locations like computer rooms, data and telecommunication centers, stores selling electronic equipment, shopping centers and Conference Halls the demand for cooling is felt all round the year. Energy is saved by providing cooling by dry coolers in winter and spring.

2.2.1.4 SAMPLE APPLICATION – 4 : Dry Cooler application for an Air Conditioning System [15]

Figure 13 shows the principle scheme of the free cooling system used in a shopping and business centre applied in Moscow.

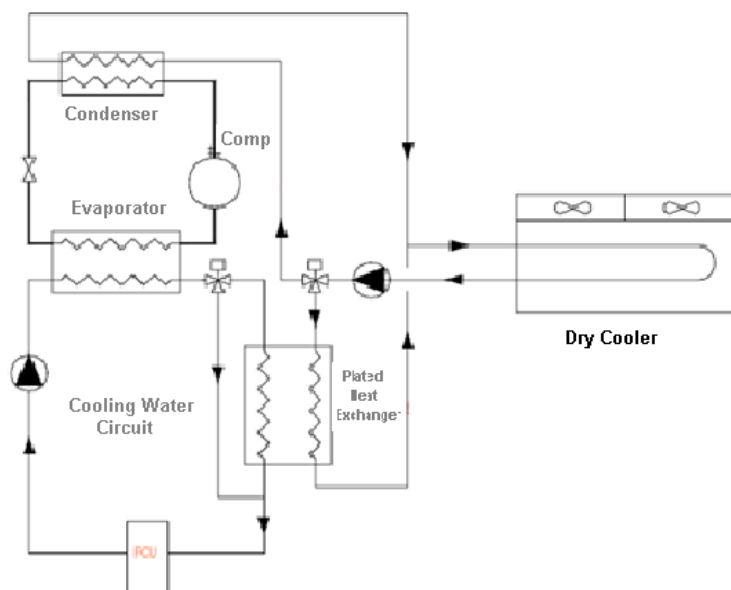


Figure 13. The principle scheme of the dry cooler installed in the shopping centre in Moscow [15]

In shopping malls, there is need for cooling in winter and spring as well. In these seasons, the cooling group is not used and the dry cooler operates for cooling (as a free cooler). The dry cooler is used in the summer season to cool the condensing water of the water cooled condenser. Since outdoor temperatures drop as far as $-30\text{ }^{\circ}\text{C}$, a high percentage of ethylene glycol (antifreeze) has been loaded into the dry cooler [15].

2.2.2 Wet/Dry Coolers

Wet-Dry Coolers operate on the same basic principle as dry coolers. There is a water sprayer system which provides additional cooling upon demand. The sprayed water leads to adiabatic cooling of the inlet air flow. When the fluid in the system must be cooled to a lower temperature than outdoor ambient temperature, the pressure water sprayer system steps in, saturating the inlet air with moisture and lowers air temperature below ambient temperature.

The water system, by coming online by thermostat control to provide additional cooling in only specific hours of the hottest days of summer, eliminates the need for an auxiliary cooling system for special circumstances. Since dry operation will be in effect at other times, the system does not have water consumption. The sprayer system can be applied to condensers of air cooled water cooling groups as well as dry coolers. Wet-dry coolers can be applied in three ways, all of which follow the same basic principle:

2.2.2.1 Direct Water Spray System Wet-Dry Coolers

The droplets of water sprayed into the inlet air by nozzles placed at regular intervals saturate the inlet air with moisture, bringing it close to the wet bulb temperature of the environment. The water used in the sprayer system should be decalcified and filtered; otherwise the lime and sediment accumulating on exchanger fins will gradually diminish the capacity and shorten the period of usefulness of the exchanger. In order to prevent this effect, the *Mesh and Spray System Wet-Dry Coolers* were developed. In Wet-Dry coolers, epoxy coated fins should be used as an additional precaution against the corrosive effect. The epoxy coating has a quite high resistance to the salt and acid in the environment. The materials preferred for the unit are epoxy dust painted galvanized sheet and for highly corrosive environments stainless steel. Although Wet-Dry Coolers are exposed to the harmful effects of water to a much lesser extent than water towers, these precautions are crucial for the longevity of these units.



Figure 14. Direct water spray system wet-dry coolers [9]

The amount of water spent in order to saturate the inlet air with moisture varies with the sprayer used and the pressure of spraying. The selection depends on the relative humidity of the ambient air; care must be taken to make sure the quantity and quality of the sprayed air is adequate for bringing the relative humidity as close to 100% as possible. For this reason, more water than will completely vaporise is sprayed and the remaining water stays in the environment in the liquid form. This precaution also provides security against losses which may evolve in time in the performance of the spraying system.

2.2.2.2 Fogging System Wet-Dry Coolers

In this application which is similar to direct water spraying systems, the droplets of water smaller than 35 microns that are sprayed under high pressure from nozzles saturate the inlet air with moisture and bring it closer to the wet bulb temperature. In this system, as in the spraying system, the water used should be decalcified and filtered.

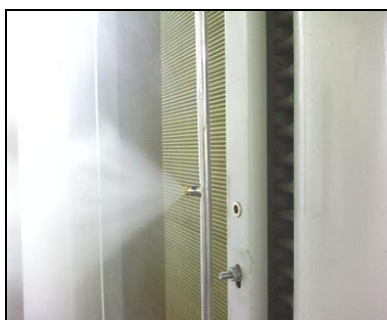


Figure 15. Fogging System Wet-Dry Cooler [9]

2.2.2.3 Mesh and Spray System Wet-Dry Coolers

The mesh and spray system involves the spraying of the amount of water that is required by the system from nozzles placed on specific positions on the wide and fine mesh material located on the front of dry coolers, and lowering the inlet air temperature coming in contact with the heat exchanger surface by the adiabatic vaporisation of the sprayed water, thus increasing the efficiency of cooling.

As explained before, the sprayed water leads to adiabatic cooling of the inlet air flow. As the specified set values are exceeded, the control system initiates the water spraying system to lower the temperature of the air entering the heat exchanger. In very arid climates, the water spraying system can provide adiabatic cooling of the inlet air which borders on 15°C to 20°C [18].

The period of operation and frequency setting of the water spray system, is continuously maintained by the controlling unit in order to achieve optimization of system performance and minimization of water consumption. Since the water is not directly sprayed on the heat exchanger surface, but rather on the mesh surface, furring does not occur on the fins. In this way, drops in heat transfer efficiency are avoided. This system also renders any water softening process superfluous.



Figure 16.A, Figure 16.B. Mesh and Spray System Wet-Dry Cooler [6]

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

The use of two speed fans, speed control devices, and Electronically controlled EC fans with automatic control will enable additional power saving for the system.

2.2.2.4 Comparison of cooling applications used in Oil Cooling Systems in the Plastics Sector

The plastics sector, from which the sample application explained in previous sections was selected, is one where cooling applications are at great demand and where free cooling applications are commonly used. For this reason, informed selection of methods to be used in cooling applications is required.

The cooling of moulds used in manufacture is important particularly for product quality. The moulds need to be kept within specific temperature ranges according to the type of plastic. Surface roughness is high and discolorations may be observed for products manufactured in moulds that are not properly cooled. Furthermore, inadequate cooling leads to extension in the opening and closing times of moulds and diminishing of production capacity. Since in cases where the ambient wet bulb temperature exceeds the temperature of the required cooling water the remaining cooling systems are not able to meet the cooling demands, the chiller group needs to be brought online to aid in mould cooling.

For machines to operate in a problem free and efficient manner, the oil used must be cooled properly as well. Otherwise, performance drops and abrasion increases. In this case, in addition to an increase in energy loss, the lifespan of the machine will shorten as well. These problems can be avoided by proper cooling of oil. On average, cooling water around 29-35°C is required for oil cooling. For economic assessment of oil cooling systems, operational costs should also be taken into consideration as well as initial investment cost. In selection of cooling alternatives, the choice that offers the greatest mid-term and long-term advantages as compared to others should be determined.

Results of the analysis made for the comparison of open and closed circuit water towers and Wet-Dry Cooler System capable of meeting the same requirements have been given below. 630 kW of heat is taken from the condenser of a cooling device. The inlet temperature of the 70%-30% water/glycol mixture into the cooler is 30°C, and the outlet temperature of the same is 26°C. The ambient temperature and relative humidity have been taken as 32°C and 38% respectively. For the analysis the unit price of water and the unit price of electricity have been taken as 1.98 €/m³, and 0.09 €/kWh respectively including VAT and similar additions. For the calculation of capital expenditure the annual

interest rate applicable to the Euro has been taken as 10% and it has been assumed that all three systems will be used for 15 years (It is also important to bear in mind that the lifespan of even towers of galvanised coating have an economic lifespan of 5 to 10 years due to their vulnerability to corrosive gases and other reasons).

THE SYSTEM EXPENDITURE	Open Circuit Water Tower	Closed Circuit Water Tower	Wet-Dry Cooler
Initial Investment Cost (€)	4,350	9,500	23,500
Water Expenses (€/year)	31,300	31,300	4,600
Electricity Expenses (€/year)	5,900	7,020	11,260
Maintenance Costs (€/year)	510	640	510
Interest Expenses (€/year)	570	1,250	3,090
Annual Total Cost of Operation (€/year)	38,280	40,210	19,460

Table 6. Economic comparison of water towers and the Wet-Dry Cooler System

Annual total cost of operation is the sum of water, electricity, interest expenses and maintenance costs. According to the above table, the Wet-Dry System pays back the difference in initial investment cost with the open circuit water tower in 1 year and the difference in initial investment costs with the closed circuit water tower in less than 1 year. At the end of these periods, the Wet-Dry Cooler system becomes economically more favourable than other systems. Since the figures used for the calculation of expenses will vary depending on the location and time of operation of the facility, the above table should be used only as a general comparison.

In places where water is plentiful and cheap, the initial investment cost may be a more important criterion than water expenses. However, in places where water is scarce and expensive the selection of the system offering the greatest economy of cooling water will be beneficial.

In the following table a chiller group meeting the 560 kW cooling requirement is compared to a Wet-Dry Cooler System capable of the meeting the same requirement in terms of monthly (over 30 days) energy expenditure. The fluid passing through the cooler needs to be cooled from 35°C to 31°C. The ambient temperature and relative humidity have been taken as 33°C and 48% respectively. It has been assumed that both systems operate 16 hours/day. The unit price of electricity has been taken as 0.09 €/kWh, VAT and other additions included.

The Chiller Unit		The Wet-Dry Cooler System
Compressor power: 136 kW	Power drawn from 16 fans: 32 kW	Power drawn from 10 fans: 20 kW
Total power: 168 kW		Total power: 20 kW
Monthly energy expenditure: 80640 kWh		Monthly energy expenditure: 9,600 kWh
Monthly expenditure: 7,258 Euros		Monthly expenditure: 864 Euros

Table 7. Economic comparison of the Water Cooling Group and the Wet-Dry Cooler System

According to the preceding table, in case the Wet-Dry Cooler System is used, the monthly savings can be calculated as 6,395 Euros. It should be kept in mind that when only coolers are taken into consideration, to the exclusion of water installation and similar investments, the investment cost of the used cooler group is approximately 61,355 Euros and that the Wet-Dry Cooler can be obtained in

exchange for an investment of 27,600 Euros. In conclusion, the Wet-Dry Cooler System is more advantageous than the cooler group both in terms of initial investment cost and operational costs.

3. DESIGN AND PERFORMANCE CRITERIA OF DRY AND WET/DRY COOLERS

3.1 Basic Design Data

There are essential design criteria which need to be observed for achieving the desired performance in a dry cooler. From another viewpoint, the information of cooling capacity without specification of some points is not meaningful.

The required data for the design and selection of dry coolers used in free cooling systems include the dimensions of the unit, the dry and wet bulb temperatures of inlet ambient air, the process inlet and outlet water temperatures, the flow of water, the required value for the water side pressure loss, the percentage of glycol and the required cooling capacity.

By knowing the design data specified above and the desired additional features, manufacturing firms may design and manufacture dry coolers 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 coils by the help of this software/program.

3.2 Coolant Properties

While 100% water may be used to meet the coolant requirement of the system, for systems operating 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 $-8\text{ }^{\circ}\text{C}$ and $-16\text{ }^{\circ}\text{C}$ respectively [5] (See Table 4, Section 2.1 and 2.2.1.1)

3.3 Standard Capacity 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).

Energy efficiency in products may be calculated for the value ranges given in the following table , as per the EUROVENT Rating Standard (For Forced Convection Air Cooled Liquid Coolers "Dry Coolers") 7/C/003 – 2007. [19]

Classes	Energy Consumption	Energy Ratio (R)*
A	Extremely low	$R \geq 110$
B	Very low	$70 \leq R < 110$
C	Low	$45 \leq R < 70$
D	Medium	$30 \leq R < 45$
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.

4. MATERIALS AND CONSTRUCTION PROPERTIES OF DRY AND WET/DRY COOLERS

The economic life of the cooling unit depends on the selection of materials that are appropriate for the operating conditions. The cooling coil within the unit in particular must be manufactured in conformity with industrial specifications.

4.1 Properties of the Cooling Coil

Cooling coils must be manufactured in conformance to the SEP (Sound Engineering Practice) defined under 97/23/EC PED (Pressure Equipment Directive).

4.1.1 Tubes

In consideration of performance and cost-friendliness, the most appropriate tubing material for cooling coils is copper. The quality of the copper used for the tubes, is among the most important properties determining the life of the dry cooler. In cases where weak material is used, problems occur particularly in inflection points and solder joints. For this reason, the copper tubes used must be manufactured per international standards. Since measurement over the product is not possible, the information regarding the wall thickness of the tube should be obtained from the manufacturer while selecting a dry cooler. Contact between the tubes and the ring plate should be avoided and long working life without leaks should be ensured in pipes.

4.1.2 Fins

The fin material commonly used in dry coolers is Aluminum. In most applications, epoxy coated Aluminum is favored for longevity of the dry cooler. The epoxy coating significantly increases the resistance of the fin to the abrasive effect of the environment. Particularly in facilities near the sea and in power plants, the epoxy coated fin application is a necessity. In highly corrosive environments where the epoxy coating may prove inadequate, epoxy and polyurethane coating is recommended.

4.1.3 Fin Geometry

In dry cooler design, fin geometry which defines the diameter of the tube and distances between tubes 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 tubing 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 practical conditions, it must be kept in mind that dry coolers having the same heat transfer surface, yet different geometries will yield different cooling capacities and pressure losses under the same conditions.

4.1.4 Casing

Dry coolers must have a self-supporting construction and allow placing on the floor where there will be installed without the aid of additional constructs.

Casing material for dry coolers is selected according to environmental conditions. In mainstream applications, galvanised steel coated with electrostatic powder paint is used as casing material. In instances where sturdier materials are required, stainless steel casing may be preferred; however this will be quite costly.

Each fan compartment should be separated from the other from plates and the reverse rotation effect of standing fans should be prevented. The placement of control covers on top of units is recommended.

4.1.5 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 speed, 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 speed to achieve the desired capacity will be superfluous and costly. In systems monitored by cooling water outlet temperature, operating fans at low speed or disabling them will provide an air supply of sufficient flow to the system.

4.1.5.1 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 intake temperature falls far below design temperatures.

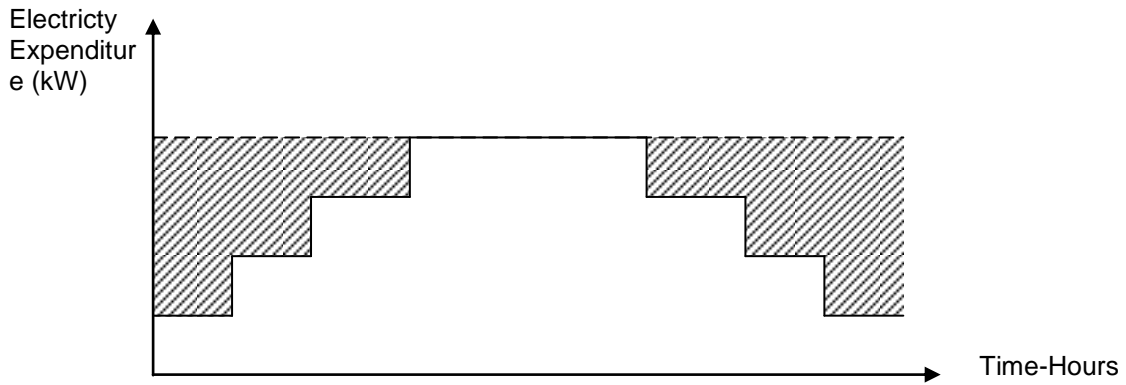
For example an 870 kW dry cooler with four fans may be operated with lowered fan rotation when ambient temperature drops from 33 °C to 20 °C. In this case, 0.75 kW less of power will be consumed per fan, which means an energy consumption of nearly 40 %. This example pertains to 4 fans, systems of a much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

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

4.1.5.2 Fan Speed 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, 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 in the hottest hours of the day and that a single fan is sufficient in the coolest hours.



Graph 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 is 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 units 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.

4.1.5.2 EC Fans [21]

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, are also used in dry cooling applications. 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 saving at nominal speed as compared to conventional speed control systems such as frequency inverter-step control-transformer frequency.

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.

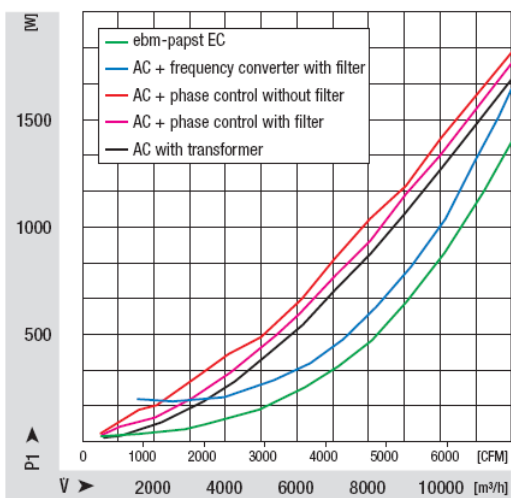


Chart 4.A EC-Motor Power Consumption [21]

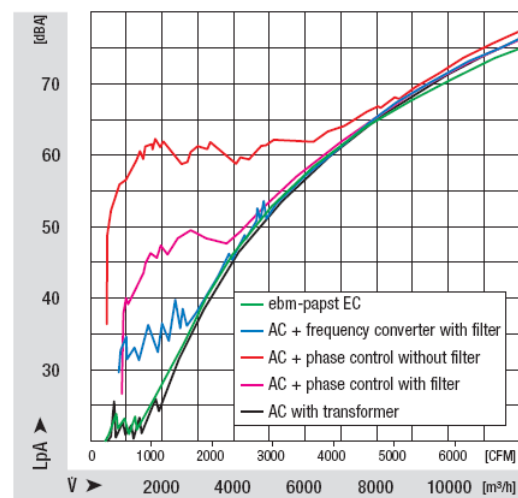


Chart 4.B EC Motor Noise Level [21]

5. CONCLUSIONS AND SUGGESTIONS

As efforts have been made to demonstrate through sundry sample applications, the efficiency gleaned from free cooling systems for water-side cooling applications is quite apparent.

Increasing efficiency, thus reducing cost per unit is a crucial edge in today's competitive environment. As the use of systems explained above in projects and applications of engineers employed in the installation sector will lead to increased efficiency in our enterprises and heighten our powers of competition as a country. 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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