ENERGY EFFICIENT FREE COOLING SYSTEMS FOR AIR CONDITIONING AND PROCESS COOLING SYSTEMS

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ABSTRACT

Increasing energy efficiency during the production, transmission and consumption of energy, in industrial enterprises, buildings, electricity generation plants, in transportation and in air conditioning facilities has have become the most important issue in our day, toward which end systems have been and are being developed to facilitate more comprehensive use of natural resources.

Free cooling systems are among the widely used energy efficiency applications. Free Cooling Systems are grouped in two categories as applications in Water-side and Air-side systems.

The system of Free Cooling which by virtue of the increase in efficiency it provides, cuts operational cost in systems requiring cooling water as well as the Chilled Beam system which is widely used in Europe and predominantly in the northern countries and which is becoming increasingly popular in other countries like the U.S.A. are effective systems in the pursuit of energy efficiency. The article provides information on the two systems, underlining the importance of energy efficiency in air conditioning installations.

1.INTRODUCTION

Free Cooling methods essentially categorized as *Water-Side Free 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 by taking advantage of the low ambient temperature.

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

1. **Evaporative Cooling Applications**
    - 1.1 Direct Free Cooling Applications
    - 1.2 Indirect Free Cooling Applications

2. **Heat Exchanger Cooling Applications**
    - 2.1 Integrated Free Cooling Coil Applications
    - 2.2 Dry 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 development stage it is of utmost importance to know the frequency of occurrence throughout the year of temperature ranges in specific periods in seasons (the BIN number). While making cost and operational analyses of systems, comparison of the required cooling water temperatures and ambient temperature values is crucial in making a healthy investment decision.

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 Chiller
- The cost of Free Cooling and the payback period
- 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. FREE COOLING SYSTEMS FOR WATER-SIDE COOLING APPLICATIONS

2.1 EVAPORATIVE COOLING APPLICATIONS

2.1.1 Direct Free Cooling Applications

In systems using cooling towers, the condenser of the cooling unit is cooled by water. The condenser is of the shell and tube type. The coolant vapour passing outside the pipes is cooled and condensed by the condenser water circulating within the pipes. In this stage, the cooling of the condenser water is done by the tower. This is how the condenser water is cooled when the chiller is operated in high outdoor temperatures. However, as the ambient temperature falls below the temperature of the cold water used in the cooling system, the cooling group no longer needs to be used. In this case, in *Direct Systems*, the chiller is bypassed and the condenser water from the tower is sent to the system directly as the cooling water required by the system. The basic advantage of this system in towers operating as open circuits can be summarised as follows: The required cold water temperature can be approximated to the wet bulb temperature of the environment. In this case, the maximum benefit will be gained from Free Cooling. However, a serious disadvantage of the system is the pollution caused by the relatively dirty condenser water in the clean cold water system. Even though attempts to alleviate pollution by methods like filtration, this system has been lately unpopular among applicators. Cooling tower applications operating as closed circuit-indirect systems or dry cooler applications catering to the same demands eliminate this problem.

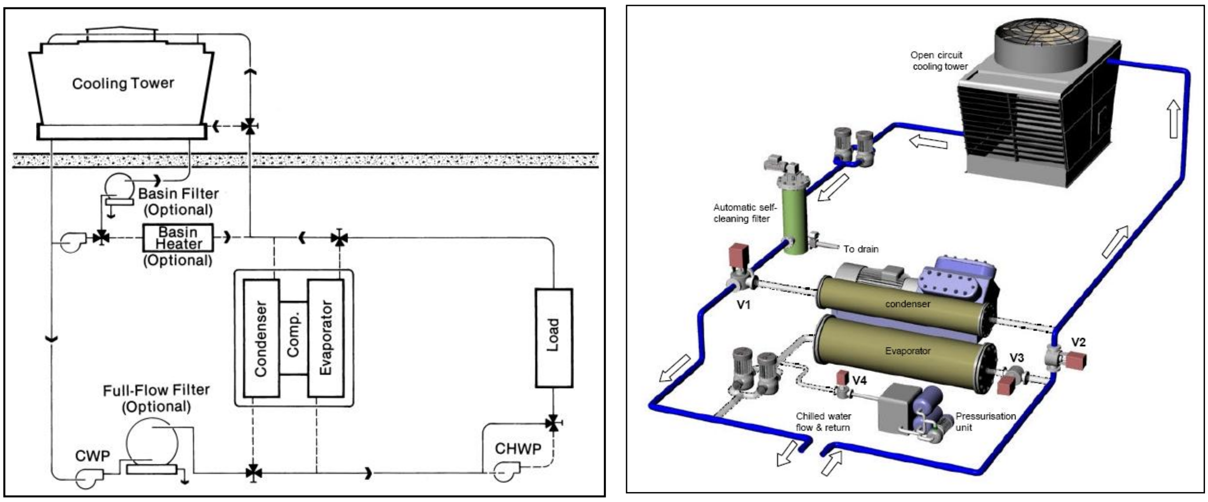


Figure 1.a – 1.b Principle schemes of Direct System-Open circuit water cooled tower systems [1],[2]

2.1.2 Indirect Free Cooling Applications

In Indirect Systems, the condenser water circuit and cold water circuit are separate. The pollution risk which is an issue in open circuit systems does not exist in indirect-closed circuit applications. However, annexing an additional heat transfer surface to the system leads to a higher water temperature as compared to open circuit water cooling towers. This cause the efficiency of Free Cooling to somewhat drop.

Indirect systems can be applied in three main ways:

1. Systems utilizing closed circuit cooling towers:

The use of Closed Circuit Cooling Towers is common in Free Cooling. As mentioned above, it eliminates the risks of pollution, etc. seen in open circuit systems. In the summer season which is the normal operating period of the cooling group, the condenser water coming from the tower circulates from the condenser within a closed circuit. In winter months however, when only Free Cooling is used, the water coming from the tower circulates in the cold water circuit within the closed circuit.

Figure 2.b shows the Load Sharing Closed Circuit Cooling Towers Free Cooling application. In this system, the returned cooling water undergoes a pre-cooling process prior to entering the evaporator. This application decreases the cooling load on the chiller. This application increases system efficiency in interim seasons.

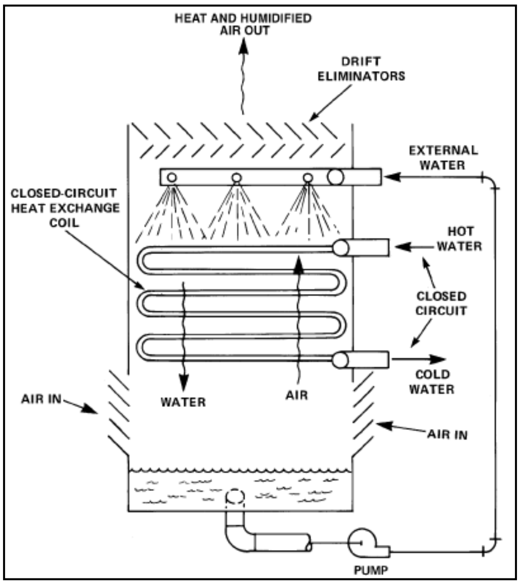


Figure 2.a

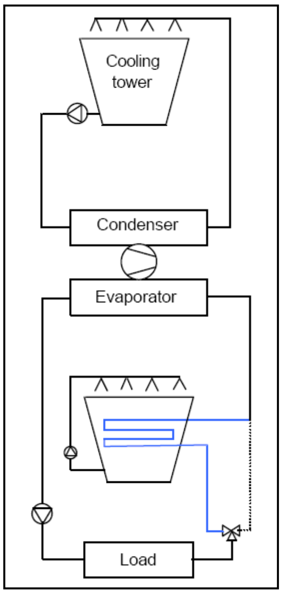


Figure 2.b

Figure 2.a Indirect – Closed Circuit Cooling tower Free Cooling application [1]
Figure 2.b Load sharing Closed Circuit Cooling Towers Free Cooling application [2]

In water cooling towers, depending on design, water can be cooled to a temperature up to 3-6ºC above wet bulb temperature. In closed circuit cooling towers, the water temperature which can be attained is up to above 2-3ºC the temperature that can be achieved with open circuit water towers. In ideal conditions wet bulb temperature can be approached closely by increasing tower dimensions; however in this case the cost of investment will increase dramatically. While water cooling towers are advantageous in terms of initial investment cost, they can lead to problems in operation. In case the water from the water tower is used directly, this causes calcification and pollution of cooling exchangers. Furthermore, the portion of the water used in water towers which is lost to evaporation needs to be constantly replenished. Additionally, the water needs to be flushed periodically in order to get rid of sedimentation within the tower tank; the water in the tank may reach extremely high degrees of hardness and pollution dues to the accumulation of scale and other similar substances in water diminished by evaporation in the system. The use of these systems should also be evaluated in terms of water loss and water quality.

2. Systems Utilizing Supplemental Heat Exchangers:

These are applications utilizing a separate heat exchanger within the system. The heat exchangers used in these cases are usually plate type ones. In the winter season, the heat load in the cold water circuit is received by the tower water through a supplemental heat exchanger without the need for a chiller.

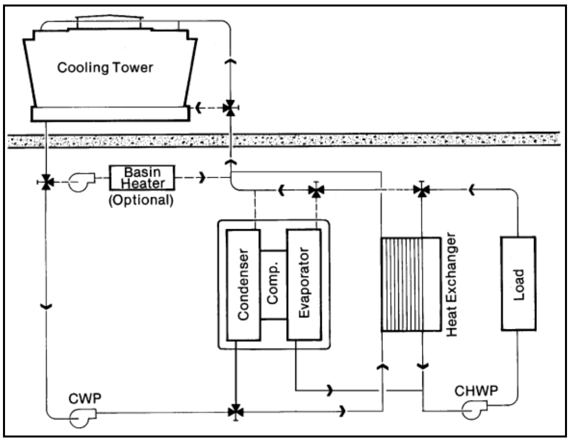


Figure 3. Systems using a supplemental heat exchanger [1]

3.* Refrigerant Gas circulation system*:

The Refrigerant Gas circulation system is one which is rarely used. In cases where the condenser water can be obtained below the desired cold water temperature, the chiller operates like a thermosyphon. The low temperature condenser water condenses the gaseous refrigerant fluid within the condenser. The condensed refrigerant fluid is transferred to the evaporator by the aid of gravity or an auxiliary pump. The high temperature cooling water circulating in the system causes the refrigerant fluid within the evaporator to vaporise. The differential pressure between the Evaporator and the Condenser causes the gas to return to the Condenser. In this system, the flow between the evaporator and the condenser is facilitated through by-pass connections. This system renders the operation of a compressor unnecessary. This system is not applicable to all cooling groups. And in groups where it is applied, the Free Cooling capacity is limited to 10-30% of the design capacity of the chiller. The Free Cooling capacity depends on the design specifications of the chiller and the temperature difference between the desired water temperature and the condenser water temperature.

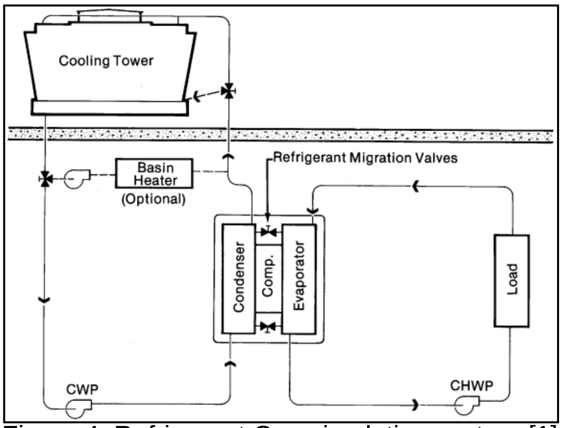


Figure 4. Refrigerant Gas circulation system [1]

2.2 COOLING APPLICATIONS WITH HEAT EXCHANGERS

In air conditioning systems, the feasibility of diverse applications for the generation of cold water required in process water cooling facilities etc. and the categorization of Free Cooling applications for these systems were discussed above. Air / Water cooled cooling groups (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 finned block heat exchanger (Cooling Coil) systems. 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 defined in three different approaches which are: entirely mechanical cooling (no Free Cooling application); partial Free Cooling (load sharing-pre-cooling) and entirely Free Cooling (the cooling group does not operate).

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. Free Cooling Chiller Applications
2. Applications of Dry and Wet/Dry Cooler Systems

2.2.1 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 dominant share of the energy expenditure in plants. As opposed to conventional chillers, integrated Free Cooling coil air conditioned water chillers have gained popularity of late. Integrated Free Cooling coil groups are items of standard manufacture in factories, Free Cooling coils can be applied to conventional groups existing in the plant by modification of the system.

Whether the plant in which Free Cooling will be utilized for air conditioning or process cooling; and whether the water circulating in the system will be exposed to below zero outdoor ambient temperatures is important for the design. While 100% water may be used to meet the cooling water requirement of the system, for operation in outdoor temperatures of below zero, a glycol-water mixture (brine) must be used to prevent freezing. (A 20% glycol mixture by weight and a 30% glycol mixture by weight provide protection down to an average of –10^{o}C and –16 ^{o}C respectively.) There are two points that should be kept in mind in case the glycol-water mixture system is used. 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 chiller 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. These points must certainly be considered prior to design, depending on the location and temperature of application.

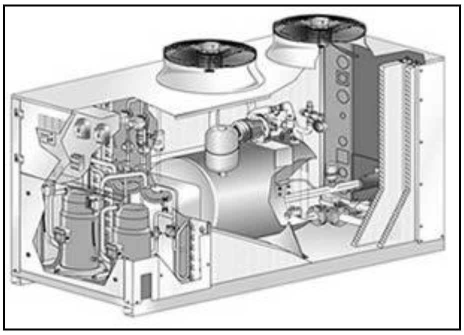


Figure 5.a

Figure 5.b

Figure 5.a Schematic for Integrated Free Cooling coil air cooled water cooling group [3]
Figure 5.a Integrated Free Cooling coil air cooled water cooling group [4]

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.

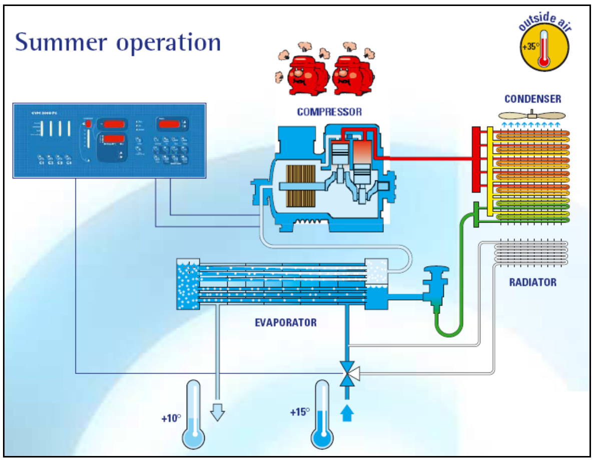


Figure 6.a Operating conditions of integrated free cooling coil air cooled chillers for the Summer Season [5]

The ambient temperature is above the desired cold water temperature and the return water temperature. (Example $T_{ambient}$: 35°C, $T_{cooling\ water}$: 10°C, $T_{return\ water}$: 15°C) The cold water required is provided solely by the operation of the cooling group within the conventional cooling cycle. The free cooling coil is not operational.

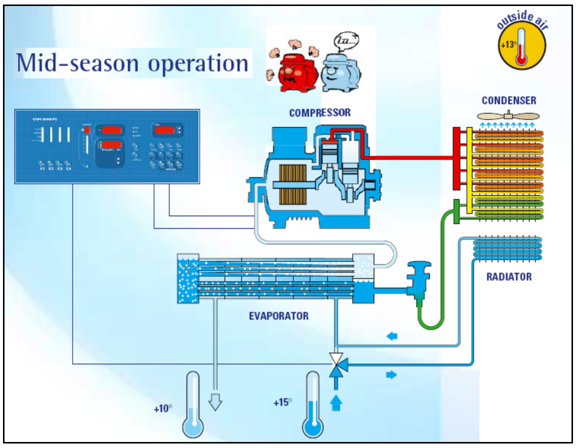


Figure 6.b Operating conditions of integrated free cooling coil air cooled chillers for the Spring Season [5]

The ambient temperature is above the desired cold water temperature and below the return water temperature. (Example $T_{ambient}$: 13°C, $T_{cooling\ water}$: 10°C, $T_{return\ water}$: 15°C) The cooling water is first pre-cooled 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.

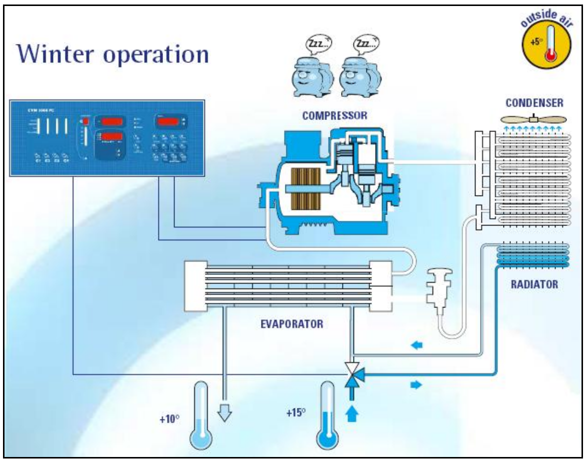


Figure 6.c Operating conditions of integrated free cooling coil air cooled chillers for the Winter Season [5]

The ambient temperature is below the desired cold water temperature and the return water temperature. (Example $T_{ambient}$: 5°C, $T_{cooling\ water}$: 10°C, $T_{return\ water}$: 15°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.

SAMPLE APPLICATION: Integrated Free Cooling coil water cooling group application

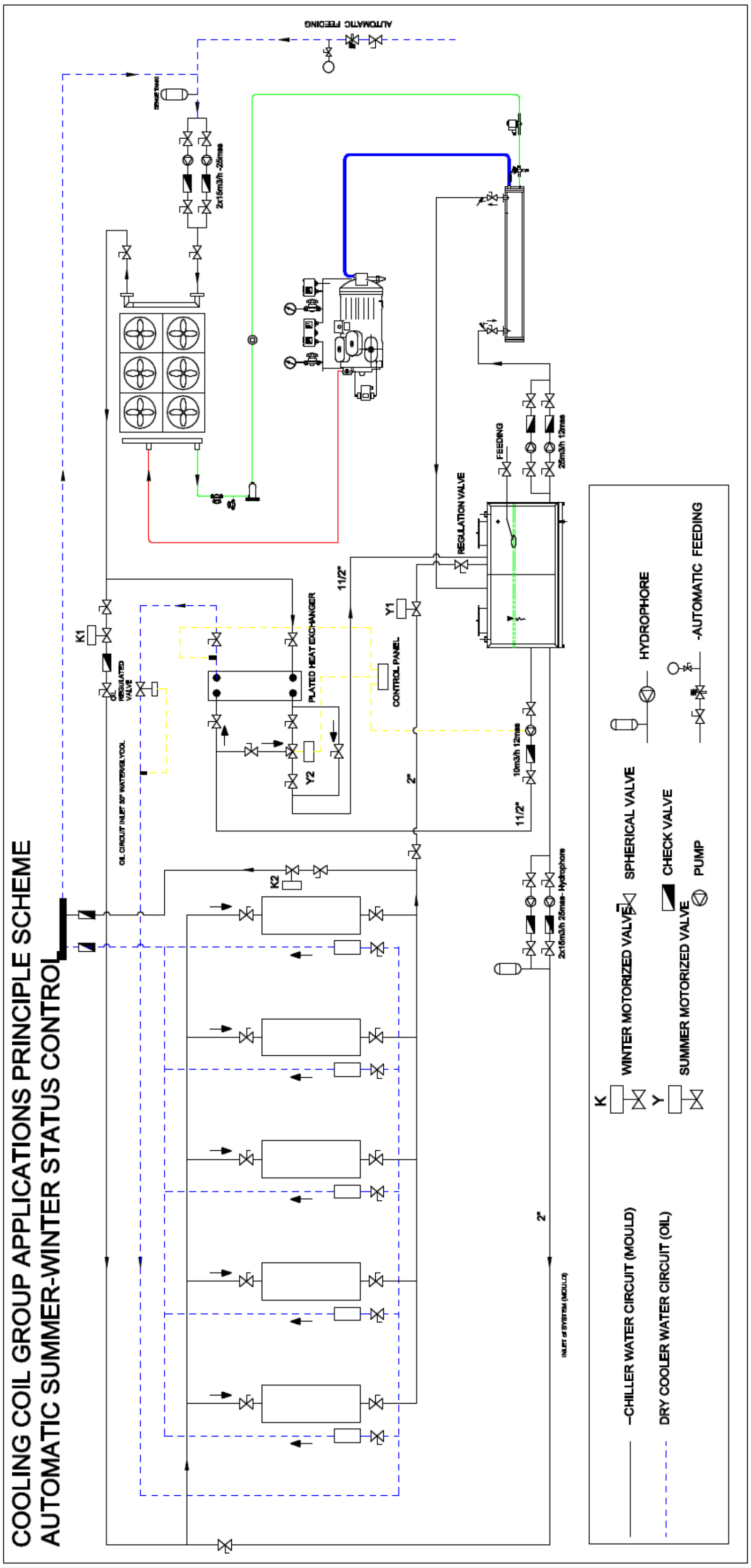


Figure 7. Principle scheme for the application of air cooled water cooling group with integrated free cooling coil [6]

The principle scheme on the left 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 following page shows the comparison made for the system.

The free cooling coil (Dry Cooling system) is located –integrated– within the same unit 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. 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 chillers with integrated cooling coil.

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 chiller group is operated. Lower limit range for the operating temperature of cooling water: 24.5ºC and the upper limit value is 26 ºC. 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 30ºC, the upper limit value: 36 ºC. 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 battery (integrated dry cooler unit) is used. The chiller group is disabled. Lower limit range for the operating temperature of cooling water: 24.5ºC and the upper limit value is 26 ºC. 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 battery (integrated dry cooler unit) is used. Lower limit range for the operating temperature of oil cooling is 24.5ºC, the upper limit value is 26.5ºC. 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					Dry Cooler				Dry Cooler		
IN CASE FREE COOLING IS NOT APPLIED												
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 employed

In the calculation of the gain from Free Cooling, the chiller already installed in the system and use of an integrated coil has been compared to the instance where Free Cooling is not used (a second cooling group is used).

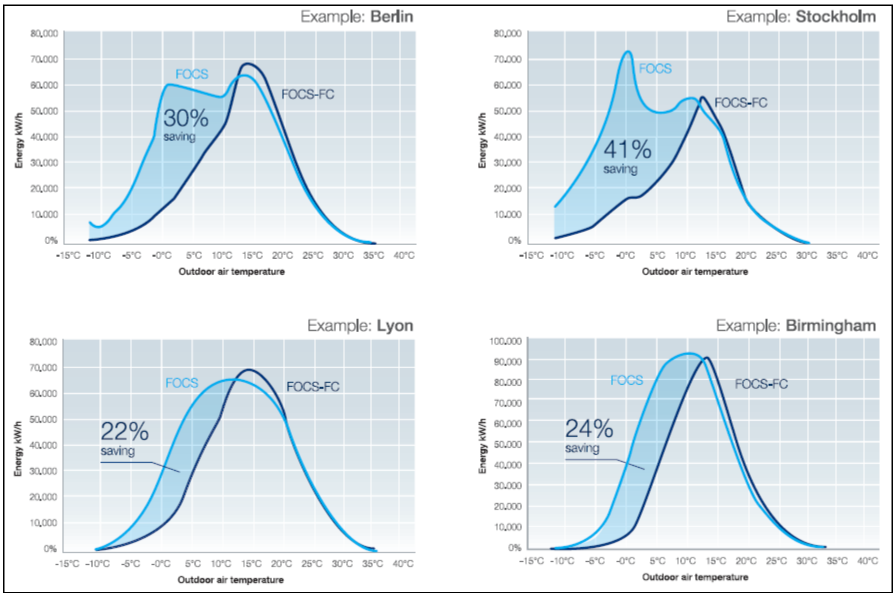
The cooling capacity needed in the system is 180 kW. In the existing state 60 kW and 120 kW of power are required for mould cooling and oil cooling respectively. Since a chiller of greater capacity than required was selected in order to accommodate further capacity requirements as they emerge within 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 (Dry Cooling system) is located within the same unit as the condenser of the air cooled group.*** The unit contains 6 high revolution Ø630 mm 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 operate18 hours each. For the analysis the unit price of electricity was assumed as 0.09 €/kWh including VAT and other additions. 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 + DRY COOLER 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 DRY COOLER)		
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

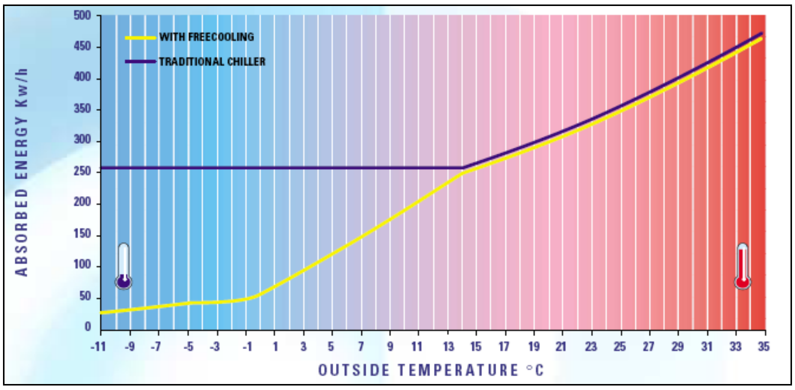
In addition to the process cooling application, the conclusions related to measurements taken in four European cities by a chiller manufacturing firm on integrated Free Cooling coil air-cooled water cooling groups in order to demonstrate the gain resulting from the use of Free Cooling in air conditioning systems have been given below in charts.



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 [7]

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 the following graph. (Outdoor ambient temperature: 30°C, T_{water} return: 10°C/15°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 1123 kW cooling capacity installed in the air conditioning system in the city of Milan [7]

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 Istanbul and as approximately 37% for the conditions of Ankara. [8]

The following table show 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 İnsolation 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 Istanbul from the T.S.M.S. [9]

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 İnsolation 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.a Temperature data over 11 years for Ankara from the T.S.M.S. [9]

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 İnsolation 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.a Temperature data over 11 years for İzmir from the T.S.M.S. [9]

2.2.2 Applications of Dry and Wet/Dry Cooler Systems

Dry Coolers:

Another shell and tube heat exchanger method used in water cooling is the system called Dry Cooler. 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 tube while it passes through the fins. In this method, the exterior surface of the exchanger is dry. In this case, problems such as calcification and corrosion do not exist. Thanks to closed circuit operation of the system, the problem of diminishing cooling water is not observed.

Measures should be taken against freezing in Dry Coolers for winter months. Otherwise, the damage to the pipes due to freezing of the internal fluid will be irreparable. In our country, the instances where Dry Coolers rendered unusable by freezing require complete replacement are quite common. 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 piping structure; antifreeze (ethylene glycol) must be added to the cooling fluid in an adequate percentage.

The glycol to be added to the cooling water must also be taken into consideration for the selection of radiators. Dry Cooler design should be made with respect to water containing 25%-35% glycol. 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 nor meaningful in the absence of the design conditions and glycol-water ratio.

Figure 8.a

Figure 8.b

Figure 8.c

Figure 8.a Flatbed Dry Cooler [6]
Figure 8.b V Coil Dry Cooler [6]
Figure 8.c Chiller and Dry Cooler application [4]

The water temperature achieved in Dry Coolers depends on the ambient dry bulb temperature; water cooled to approximately 5 ºC above dry bulb temperature can be generated. In cased where cooling water at lower temperatures is needed, Wet-Dry Coolers are used.

These systems operate under the same principle as the previously explained Free Cooling coil systems. If a chiller 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 are 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 the water cooling requirements.

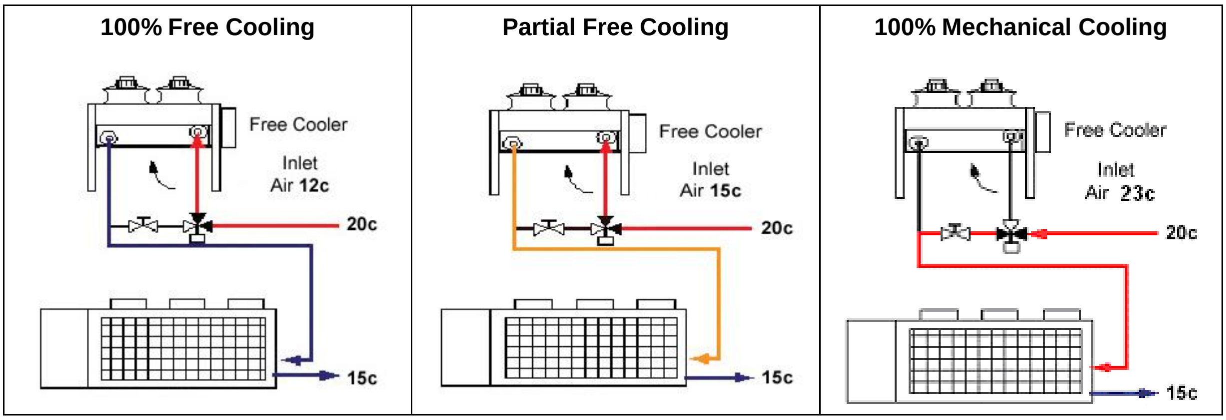


Figure 9 Schematic representation of a Dry Cooler application with a Cooling Group [10]

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 becoming active by thermostat control to provide additional cooling in only specific hours of the hottest days of summer, removing 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 spryer system can also be applied to condensers of air cooled water cooling groups as well as dry coolers. Wet-dry coolers can be applied in three different ways whose basic principles are the same:

1. Direct Water Spray System Wet-Dry Coolers:

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 towrs, these precautions are crucial for longevity of these units.

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.

Figure 10. Direct water spray system wet-dry coolers [6]

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 11. The Fogging System Wet-Dry Cooler [6]

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 efficiency of cooling.

As explained below, 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 (ambient) air which borders on 15˚C to 20˚C. 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 12. 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 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. The use of double rotation fans, speed control devices, and electronically controlled EC fans with automatic control will enable additional power saving for the system.

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

The plastics industry, from which the sample application explained in the previous section 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. Cooling water around 29-35ºC 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 30ºC, and the outlet temperature of the same is 26ºC. The ambient temperature and relative humidity have been taken as 32ºC 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 life 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 4. 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 graph, the Wet-Dry System amortisation period 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 Coolers become 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 35ºC to 31ºC. The ambient temperature and relative humidity have been taken as 33ºC 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 including VAT and other additions.

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: 80,640 kWh		Monthly energy expenditure: 9,600 kWh
Monthly expenditure: 7,258 Euros		Monthly expenditure: 864 Euros

Table 5. Economic comparison of the Water Cooling Group (Chiller) and the Wet-Dry Cooler System

According to the preceding table, in case the Wet-Dry Cooler System is used, the monthly gain 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 chiller 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 chiller group both in terms of initial investment cost and operational costs.

4. FREE COOLING APPLICATION IN CHILLED BEAM SYSTEMS

The Chilled Beam system which is widely used in Europe, particularly in northern countries and which is becoming increasingly popular in U.S.A and other countries is a quite effective system which creates energy efficiency by facilitating reduction of the central conditioning unit without lowering interior air quality. The use of Free Cooling applications in these systems saves more energy than low temperature chiller applications due to higher cooling water temperatures. The Chilled Beam can be defined as a conditioning device which includes a shell and tube water coil and which operates on a different principle than air diffusers used in mainstream applications. In these products, heating is also possible by circulation of hot water in the water installation.

Chilled Beam applications fall in two basic categories which are "passive" and "active".

The Passive Chilled Beam system:

In the system called Passive Chilled Beam, heat transfer is made basically through natural convection and radiation. The Passive Chilled Beam unit consists of a shell and tube heat exchanger (cooling coil) placed within a casing. In applications, aluminium is widely used as fin material, and copper is widely used as tube material. The cold water obtained from the central water cooling unit circulates within the water cooling coil. In the meantime, ambient air flowing between fins moves from the upper portion of the room to the lower portion. The air within the room travels upward upon becoming warmer. The cooling capacity depends on the difference between the temperature of the cooling coil and that of the room.

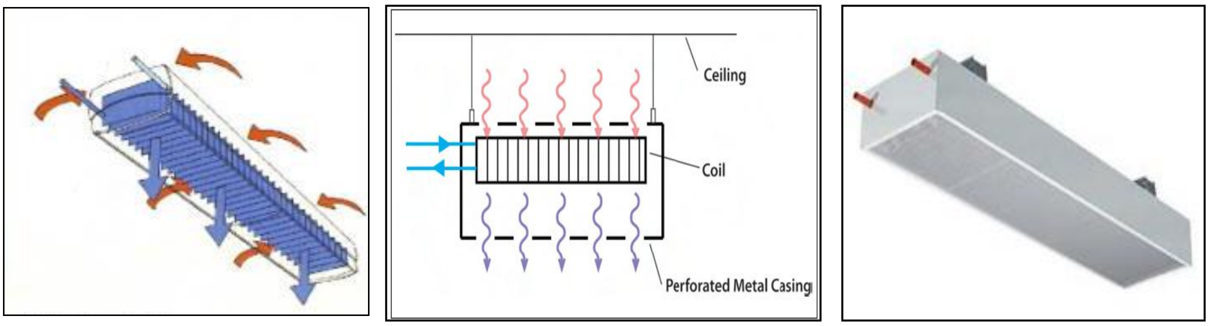


Figure 13. Passive Chilled Beam unit [11],[12],[13]

The Active Chilled Beam system:

In the system called the Active Chilled Beam, the unit depends on fresh air feeding channels and the cool water line. The pre-conditioned air provided from the central air conditioning unit is blown from the small air jets within the unit, creating air movement in the room away from the unit. This movement of air causes the air within the room to flow within the unit and it is cooled with heat exchangers. The movement of air within the room also mixes fresh air with the air circulating within the room. While their large size comes with higher cost as compared to conventional diffusers, the advantage in operational costs which it provides, renders this disadvantage unimportant.

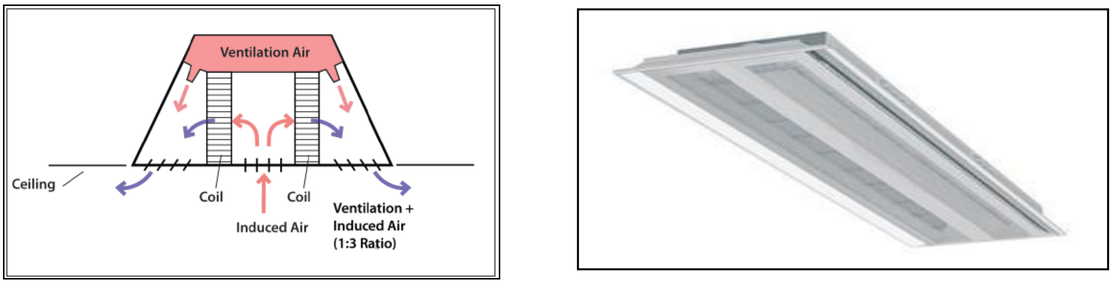


Figure 14. Active Chilled Beam unit [11],[12],[13]

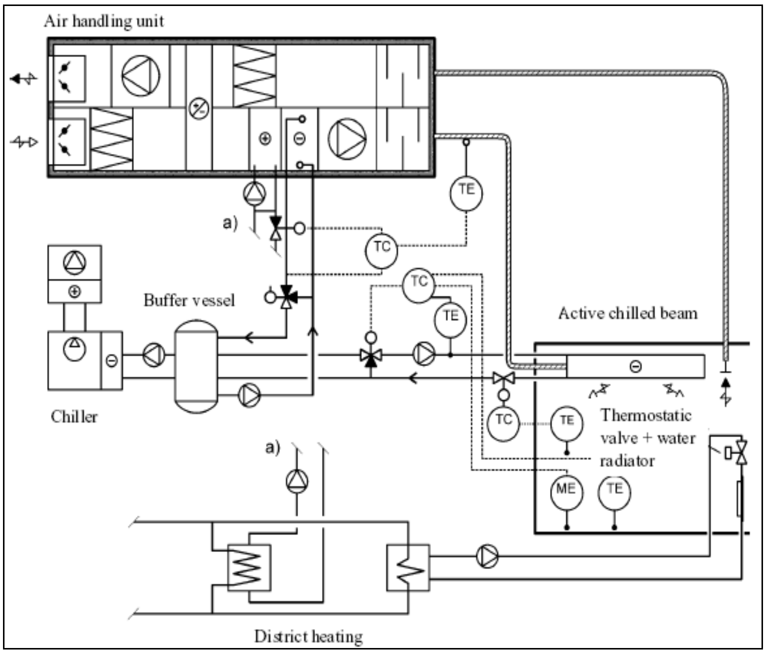
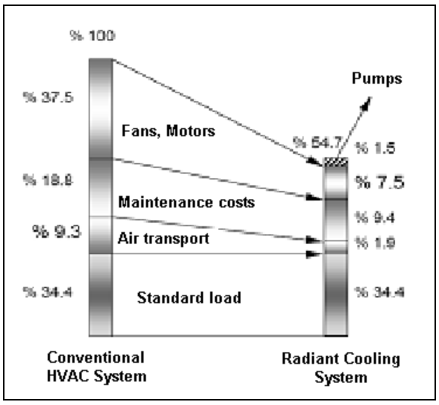


Figure 15. The Cative Chilled Beam unit design [11]

In cases where the amount of air needed to carry the required cold energy is greater than the fresh air requirement, the chilled beam system significantly reduces the amount of circulating air, reducing the capacity of central conditioning device. Since these systems provide for the perceptible cooling requirement of the space and reduce the total cooling requirement of the system, separating the cooling requirement from ventilation and moisture control, they enable downsizing of central air conditioning units thus reducing initial investment and operational costs. Since the system has perceptible operation, the chiller group operates at high water temperatures, facilitating Free Cooling and reduction the cost of operation. Another effect of perceptible operation conditions is eliminating the need of a drainage installation.

The following figure shows the effect of the chilled beam system on efficiency by the results of two comparisons.



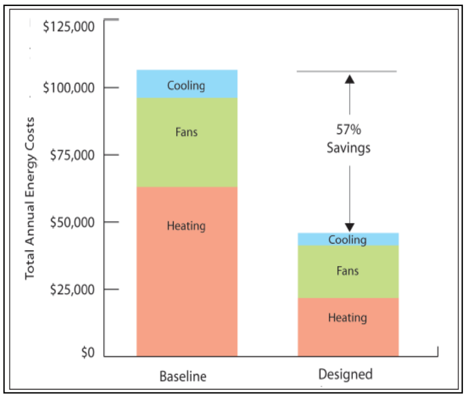


Figure 16.

Graph 3.

Figure 16. Comparison of conventional HVAC installations with the Chilled Beam system with respect to energy [14]

Graph .3 The comparison of the Chilled Beam application installed in the Tahoe Environmental Research Center (Incline Village, Nevada, U.S.A.) with conventional HVAC installation with respect to total annual energy expenditure [12]

Uses of Chilled Beam systems:

The use of active chilled beam systems is recommended for the following venues:

- Partitioned and open office spaces
- Hotel rooms
- Hospitals
- Stores
- Banks
- Laboratories

However, these applications are not recommended for spaces like conference halls, meeting rooms, classrooms, etc. where high ventilation loads are required.

Operating range of the Chilled Beam System:

The Active Chilled Beam system can be applied in spaces where the total perceptible cooling requirement is below 120 W/floor space-m^2. The optimum working range is 60-80 W/floor area-m^2'dir. The passive chilled beam system can be applied in spaces where the total perceptible cooling requirement is 40-80 W/floor area-m^2. The targeted indoor ambient temperature in summer conditions is 23-26ºC.

Free Cooling and the Chilled Beam System

In the chilled beam system, high temperature cooling water is used in order to avoid condensation. The temperature of the water circulating in the coil in order to cool the room is typically 14-18 ºC. (The temperature of the circulating water for heating is 30-45ºC.) High cooling water temperature leads to use of a lower capacity cooling group in the system. In this case, both the initial investment and operational costs are reduced. [14]

Since Free Cooling systems are operated with higher cooling water values than operating at 6/11ºC or 7/12ºC, Free Cooling systems used for cooling water can be installed in places where chilled beam units exist.

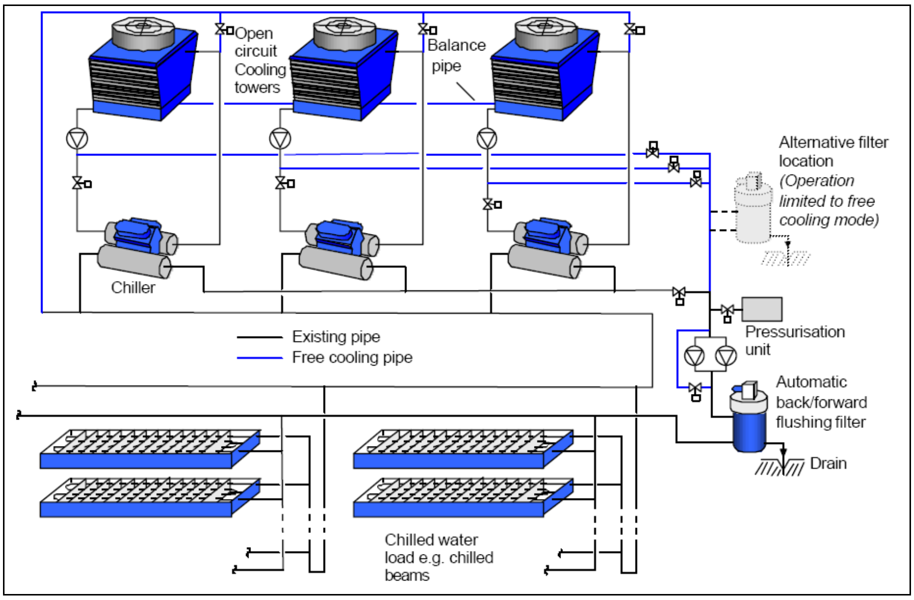


Figure 17. The Chilled Beam system and open circuit cooling tower Free Cooling application [2]

Free Cooling application in Chilled Beam systems can be made by various methods, including:

- Dry Cooler application
- Cooling Tower application
- Underground energy storage systems application

Figure 17 shows the Chilled Beam system and open circuit cooling tower Free Cooling application. Dry coolers can be used instead of a water tower in this application. Free Cooling applications in Chilled Beam systems provide additional efficiency.

CONCLUSIONS AND SUGGESTIONS

As explained above with various sample applications, the efficiency provided by Free Cooling Systems for Water Cooling Applications and Chilled Beam Systems which are gaining increasing popularity are evident.

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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