LT-HT RADIATORS USED IN POWER PLANTS (DRY COOLERS)

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ABSTRACT

Dry Coolers (Radiators) are widely used in the energy sector for the expulsion of waste heat from the system. For hassle free cooling of machines like motors and combustion turbines in a power plant, and for healthy operation of the system, the Dry Coolers to be used must be selected carefully. This paper discusses the basic points that should be taken into consideration in selecting a cost-friendly and durable Dry Cooler, capable of providing the required cooling capacity at high performance, by offering practical values to be used in selection. The scope of the paper includes information on the materials, design criteria and fans commonly used for Dry Coolers, as well as an introduction to LT-HT Radiators and Dry Coolers –which have an important place in the energy sector- with a focus on practical application.

SUMMARY

Dry-Coolers are frequently used in power plants, and therefore should be chosen carefully. The copper tubes should be at least 0,50 mm thick, and the fins would rather be about 0,14 mm thick for general purposes. Gold epoxy or gold epoxy + polyurethane coating should be preferred for fins. The casing should be electrostatically painted galvanized steel or stainless steel.

Inlet air temperature and the air flow rate of the fans used are excessively effective on the cooling capacity obtained. For example, the obtained cooling capacity of an HT Cooler may be 83 % of the declared capacity, if the capacity declared is for 25 ºC inlet air, and the actual inlet air temperature is 35 ºC. This ratio may be about 37 % for an LT Cooler, as in the example. Therefore, these parameters should be checked first when choosing a Dry-Cooler. Also, the ratio of glycol in the cooling water is very important. If the glycol ratio is not enough, the cooling water may freeze when it is cold, and the cooler may be damaged irreversibly. The design should be for around 30 % glycol for general use.

For cooling Jacket Water and After Cooler waters, LT-HT Radiators are preferred for lower electrical expenditures. Initial costs of LT-HT Coolers are also comparable with separate LT and HT Coolers.

For emergency cooling, Wet-Dry Coolers are used, where water spraying system is activated automatically when needed and the inlet air is cooled down nearly to the wet-bulb temperature of the surroundings.

Two-speed fan motors, step controls and frequency inverters/converters are used for speed regulation of the fans.

1. MATERIAL

The economic life of the Dry Cooler depends on selection of materials that are appropriate for operating conditions.

1.1. Tube

In consideration of performance and cost-friendliness, the most appropriate tube material for Dry Coolers 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.

Another point which requires consideration is the wall thickness of the tube. The wall thickness of copper should not be less than 0.5 mm in Dry Coolers. In special conditions 0.7 mm can be preferred. Since measurement on 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.

1.2. Fin

The fin material commonly used in Dry Coolers is Aluminum.

Depending on the location of use, a fin thickness of 0.14-0.15 will be appropriate. In special applications, the use of thicker fins is also possible. Fins thinner than 0.12 mm should not be considered for dry cooler applications.

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.

1.3. Casing

Casing material for dry coolers is selected according to environmental conditions.

For general purposes, galvanised sheet is used as casing material. Galvanised sheet is inadequate for meeting requirements in the absence of further protective measures. Hot dipping is not recommended since it causes deformation. Application of powder paint on galvanised sheet will be the most advantageous choice.

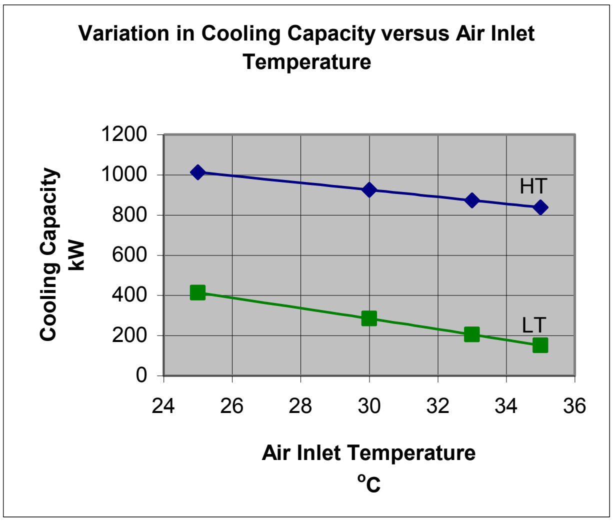
In instances where more durable material is required, stainless steel casing is preferred.

2. DESIGN CRITERIA

There are essential design data and 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.

2.1. Ambient Conditions

The cooling capacity of a Dry Cooler can only be determined by knowing the conditions of its operating environment. The most important criterion regarding the environment is the air inlet temperature. For example, the cooling capacities for various air inlet temperatures for a HT (Jacket Water) refrigerating Dry Cooler operating at 99ºC / 73ºC and for a LT (After Cooler) refrigerating Dry Cooler operating at 44ºC / 39ºC have been given in the following chart. An important point to be considered for Dry Cooler selection is the necessity to know the cooling capacity of the Dry Cooler to be purchased in the conditions of the area in which it will be operated. In the current example, the HT Dry Cooler purchased according to its cooling capacity for an air inlet temperature of 25 ºC, yields 83% of the required capacity when operated in its actual operating venue with an air inlet temperature of 35 ºC, this percentage is a mere 37% for a LT Dry Cooler.



Graph 1. Variation in cooling capacity versus air inlet temperature [2]

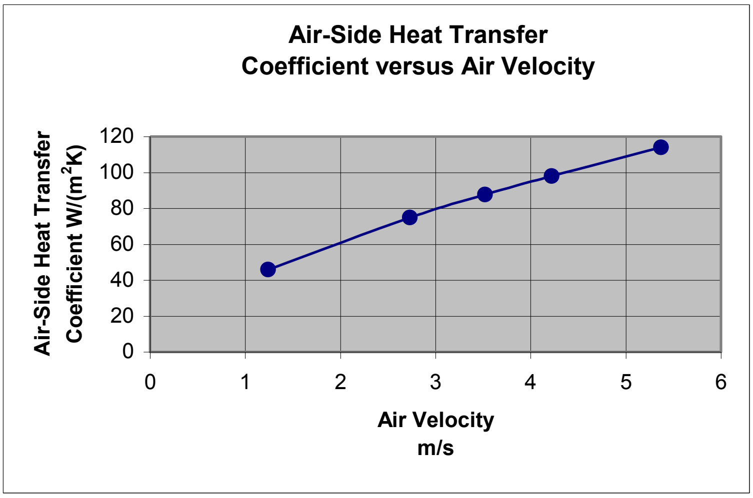
Note: This capacity calculation and subsequent ones have been made using the COILS 5.5 FRT1 software.

2.2. 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.

2.3. Air Velocity

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



Graph 2. Air-side heat transfer coefficient versus air velocity

2.4. Internal Coolant

Measures should be taken against freezing in Dry Coolers for winter months. Otherwise, the damage to the tubes due to freezing of the internal fluid will be very difficult to repair. 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 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 tubing structure; thus 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 not meaningful in the absence of the design conditions and glycol-water ratio.

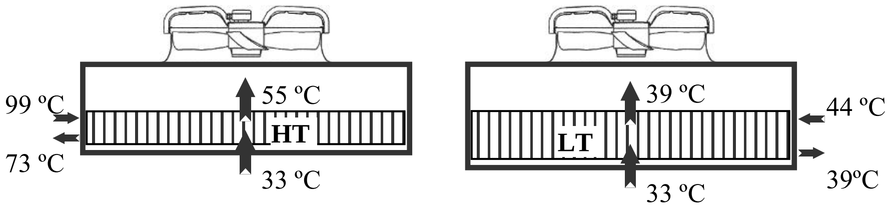
2.5. Noise Level

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. If needed, the sound level may be reduced by decreasing motor rotation; in this case the heat transfer area of the heat exchanger should be increased in order to provide the required cooling capacity.

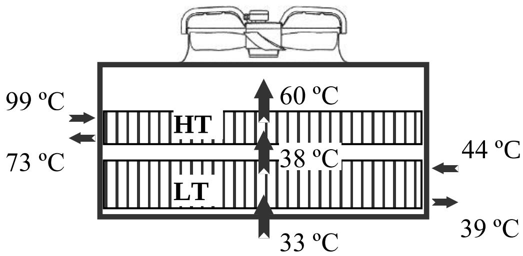
3. THE LT-HT RADIATOR

Picture 1. An LT-HT Radiator

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



Picture 2. The cooling of HT (Jacket Water) and LT (After Cooler) circuits with separate dry coolers



Picture 3. The cooling of HT (Jacket Water) and LT (After Cooler) circuits with the same dry cooler unit

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

Example:

A selection will be made for HT and LT radiators that will be used in Istanbul; according to the figures in the following table (the glycol/water ratio is 30%).

The required	HT Radiator	LT Radiator
Cooling Capacity	805 kW + 10 % security	185 kW + 10 % security
Water Inlet Temperature	99 ºC	44 ºC
Water Outlet Temperature	73 ºC	39 ºC

For Istanbul Dry-Bulb Temperature = 33 ºC
Wet-Bulb Temperature = 24 ºC

For the instance that HT and LT Radiators are built separately, the radiators designed according to the desired specifications have been presented below.

The Selected	HT Radiator	LT Radiator	Total
Cooling Capacity	888 kW	205 kW	
Water Inlet Temperature	99 ºC	44 ºC	
Water Outlet Temperature	73 ºC	39 ºC	
Heat transfer surface	326 m^2	652 m^2	978 m^2
Number of Fans	6 x Ø800 mm	6 x Ø800 mm	12 x Ø800 mm

For the instance that an LT-HT Radiator is used, the radiator designed according to the desired specifications has been presented below.

The Selected	HT Circuit	LT Circuit	Total
Cooling Capacity	936 kW	203 kW	
Water Inlet Temperature	99 ºC	44 ºC	
Water Outlet Temperature	73 ºC	39 ºC	
Heat transfer surface	435 m^2	652 m^2	1087 m^2
Number of Fans	8 x Ø800 mm		8 x Ø800 mm

The power drawn by the used fans is 2 kW per fan. In case the LT-HT Radiator is preferred as opposed to separate construction of HT and LT Radiators the number of used fans is 4 less; in which case the total power drawn by the fans decreases by 8 kW (33%). In the instance where the LT-HT Radiator is used, the increase in the heat transfer surface is 11%.

The following table has been prepared in order to convey a general idea on costs. The assumptions made to simplify the study have been attached.

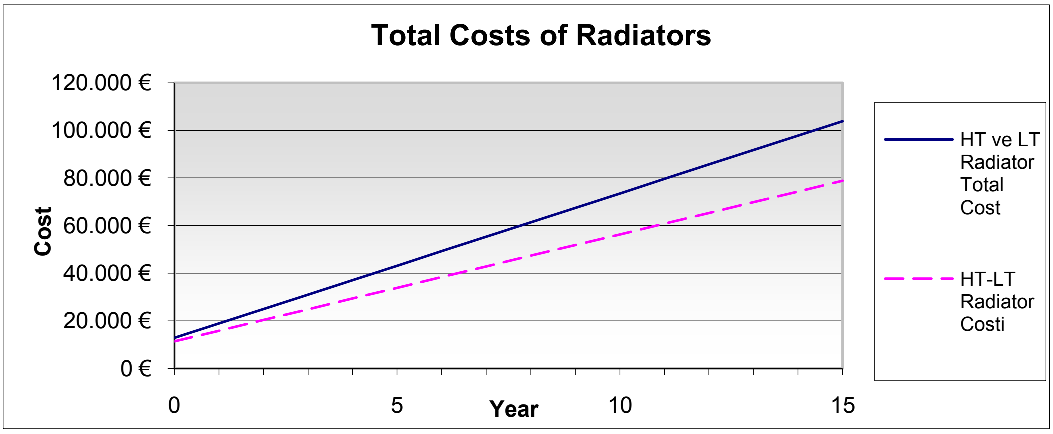
	The HT Radiator	The LT Radiator	Total	The LT-HT Radiator
Initial Investment	€5,230	€7,545	€12,775	€11,325

Operation (15 Years)	€40,500	€50,625	€91,125	€67,500
Total	€ 45,730	€58,170	€103,900	€78,825

Assumptions:

Daily Working Time:	15 hours/day	
Monthly Working Time:	25 days/month	
Yearly Working Time:	10 months/year (8 months/year for the HT Radiator)	
Unit Cost of Electricity:	0.075 €/kWh	
Radiators	Fin:	Epoxy coated Aluminum; 0.15 mm
	Casing:	Galvanised sheet painted with RAL 7044
	Paco switches on all fans	

Since the example presented above is not meant for analysis, a detailed calculation has not been made. Nevertheless, it is adequate to demonstrate the advantage of using LT-HT Radiators for operational costs. As seen in the example, the initial investment cost of an LT-HT Radiator can be less than the initial investment cost for the scenario when HT and LT Radiators are built separately.



Total Cost of HT and LT Radiators
The Cost of an HT-LT Radiator

Graph 3. Variation in total cost (initial investment +operational) in years in cases where HT and LT radiators are built separately or in conjunction (the LT-HT Radiator)

4. THE WET-DRY COOLER

Picture 4. Direct water spray system wet-dry cooler

Picture 5. Ecomesh spraying system wet-dry cooler

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.

Wet-Dry Coolers operate on the same basic principle as Dry Coolers. There is a water sprayer system which provides additional cooling upon demand. 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 sprayer system comes online by thermostat control to provide additional cooling in only specific hours of the hottest days of summer. There is no water consumption in the system in other times.

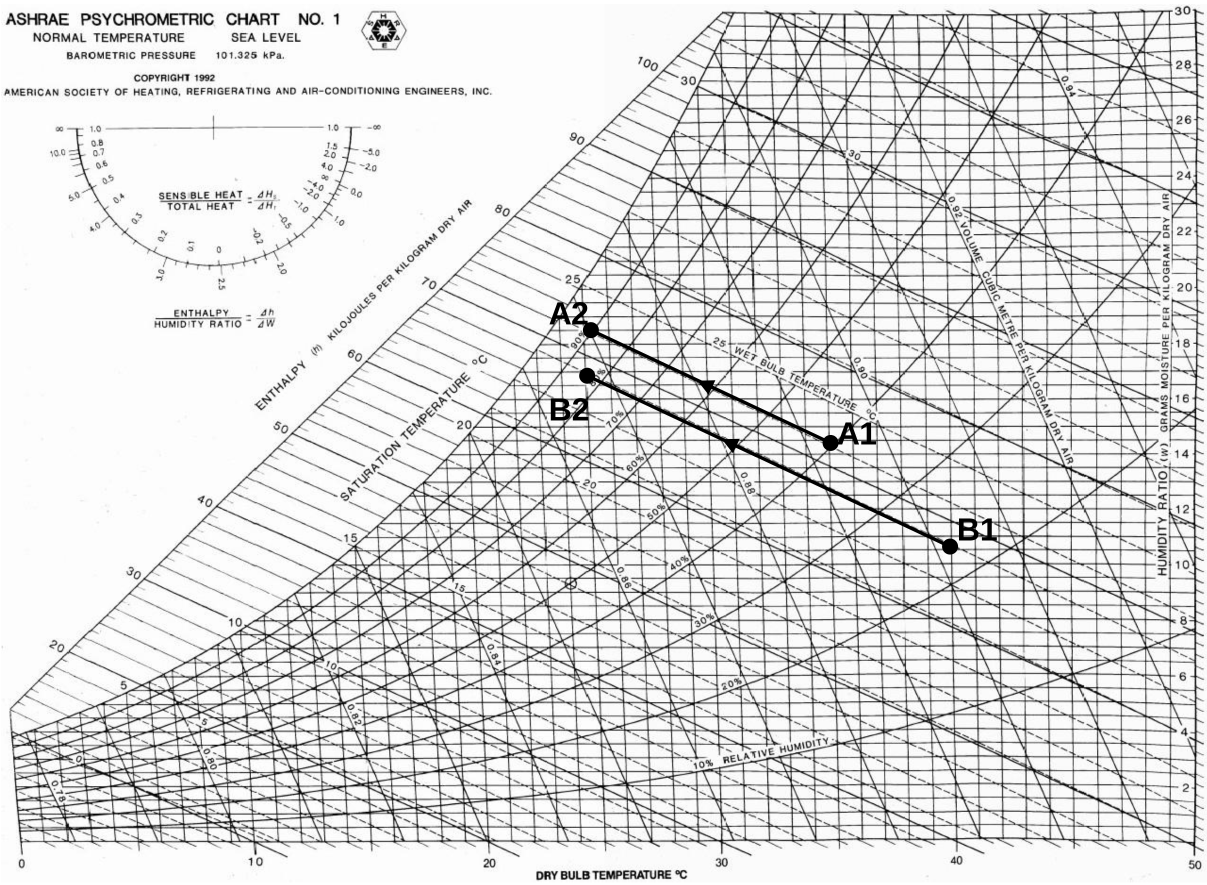
The water used in the sprayer system should be decalcified and filtered; otherwise the lime and sediment accumulating on exchanger fins will gradually diminish the capacity and shorten the period of usefulness of the exchanger. In order to prevent this effect, the Ecomesh spraying system where water is sprayed over a mesh system was 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. Stainless steel frames are preferred. 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.

Wet-Dry Coolers can be viewed as Dry Coolers where the water spraying system comes online in emergencies. Thanks to this system, an auxiliary cooling system is no longer required for special circumstances where the ambient temperature becomes too high to obtain the required cooling capacity from the Dry Cooler.

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. Taking into consideration the Ø800 mm diameter fans used in the samples in this paper, it will be enough to spray 124 kg/hour of water per fan, for general purposes. This value can be achieved with a 2 bar spraying pressure; when the system is operated at 4 bars, it can spray 173kg/hour of water. Since the water spraying system will be rarely used and will eliminate the need for additional investment of an auxiliary cooling unit for emergencies, the cost of sprayed water stays within acceptable limits for most applications.

For example, it is possible to drop the temperature of inlet air from 35 ºC dry- and 24 ºC wet-bulb temperature (40% relative humidity) to 25 ºC by saturating it to 90% relative humidity by spraying water (Graph 4, A1-A2). In this case, the cooling capacity of the HT Radiator and the LT Radiator in the example that was examined to demonstrate the variation in cooling capacity as a function of air inlet temperature under section “2.1 Ambient Conditions” increase by 20 % and 170 % respectively. The required increase in humidity, which is around 4 g/kg of air can be provided by vaporization of 90 kg/hour of water per fan capable of 22,500 kg/hour air flow at 100 Pa pressure loss; this value can be safely attained with a spraying pressure of 2 bars.

In cases where inlet air drier, the spraying system of the Wet-Dry Cooler delivers higher performance. For example, it is possible to drop the temperature of inlet air (24% relative humidity) from 40 ºC dry- and 23 ºC wet-bulb temperature (40% relative humidity) to 25 ºC by saturating it to 85% relative humidity by spraying water (Graph 4, B1-B2). The required increase in humidity, which is around 6.5 g/kg of air can be provided by vaporization of 146 kg/hour of water per fan capable of 22,500 kg/hour air flow at 100 Pa pressure loss; this value can be attained with a spraying pressure of 4 bars.



Graph 4. Adiabatic cooling of the inlet air as a result of spraying in the Wet-Dry Cooler (Psychrometric Chart [1])

5. FANS

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 lower, 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.

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 ¾ths 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 HT2 Radiator may be operated with lowered fan rotation when ambient temperature drops from 33 ºC to 20 ºC. In this case, 0.75 kW less of power will be consumed per fan, which means an energy consumption of nearly 40 %. This example pertains to 4 fans, systems of a much higher number of fans are being operated in most plants.

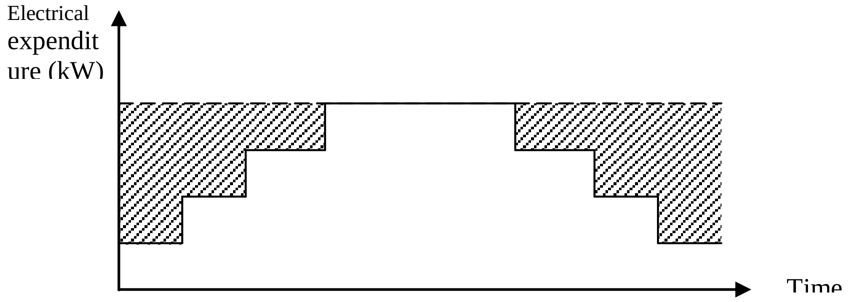
The power used by the 800 mm fans used in the example in both rotations:

880 d/d	2.00 kW
660 d/d	1.25 kW

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 5. 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 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 unit in terms of initial investment cost; therefore the systems that are widely preferred are those where fans are controlled in groups and step control units and frequency inverters/converters are used together, as opposed to systems where all fans are controlled by separate frequency inverters/converters.

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[1] ASHRAE Handbook, 2001 Fundamentals, SI Edition, F06,11
[2] Friterm Technical Documents

AUTHOR BIOGRAPHY

Hasan ACÜL was born in Ayvalik, located in Aegean region of Turkey, in 1976. He graduated from Mechanical Engineering Department of Yıldız Technical University in 1999. He has worked in sales, manufacturing and R&D departments of several companies in Heating, Cooling, Air Conditioning and Refrigeration (HVAC-R) industry. Currently, he is working as Chief Engineer of Research and Development (R&D) Department in FRITERM A.S, Turkey and studying for his master's degree in Science and Technology Strategies Department at Gebze Institute of Technology. He is an active member of The Chamber of Mechanical Engineers in Turkey. Hasan Acül has married and has one daughter.