

Free Cooling in the Water Cooling Towers: a Case Study for Istanbul, Turkey

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ABSTRACT

Energy saving in cooling towers which is used for cooling to the hot water can be significantly improved by using free cooling application. This application is commonly known economizer cycle and when outside conditions are suitable for cooling, it is used for. In this study, the free cooling is applied for the cold water necessity which is supplied by the chiller of the cooling tower in the factory which is available in Istanbul. The results show that the electricity consumption is decreased when the free cooling is applied with the chiller for industrial plant.

Key Words: *Free cooling, Energy saving, Economizer, Istanbul*

1. INTRODUCTION

Demand for energy is increasing exponentially in parallel with the development of technology and the industry rapidly. To the limited energy resources, environmental factors and costs due to the rise of increasingly important. In addition, energy consumption of air-conditioning shows an increasing trend [1]. For reducing energy consumption in industry and buildings many solutions have been suggested.

There are four basic system categories: all-air systems, air and water-systems, all-water systems and packaged unitary equipment systems [2]. Free cooling system in the cooling tower is applied to reduce the cost of production of cold water which is obtained from the chiller. The free cooling in systems which are required the cooling water is achieved at the low temperature of the ambient air. Free cooling system is one of the ways to reduce the energy consumption of a water cooling system. The outside air conditions in the free cooling

applications are determined with the temperature control or enthalpy control [3]. Temperature control is much simpler than the enthalpy control. Therefore, it is preferred. Free cooling alone is not an alternative to mechanical cooling systems. It is a system that should be considered as supportive and complementary to the mechanical system [4]. While the outdoor air in the full air systems is being sent directly to the media, it is used for the hot water cooling to increase the performance of system in water systems [5]. Free cooling for the cooling application with water is categorized in two groups. These are evaporator and heat exchanger cooling applications. Both systems have their advantages and disadvantages. One of the most important factors that will determine the selection of the system, causing the cooling system is used or to be used. The other important factor is the climate characteristics of the residential area where is the running of the system. Ambient temperature changes, is important for free cooling applications. Therefore, temperature values in a certain time period in the

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seasons which are cooling requirement along the year should be determined and be evaluated. Comparison of ambient temperature and the desired cooling water temperature is important for economic analysis.

2. CLIMATE DATA ACQUISITION

The potential for natural cooling is needed to determine the hourly temperature values. The equations which are obtained according to 15 year climate data are used in determining the temperature values [6]. These equations depend on the daily maximum and minimum temperatures and the declination angle and the latitude.

$$T_{max} = T_1 - (T_1 - T_2) \cos \left[\frac{2\pi}{365} (n - 25) \right] \tag{2.1}$$

$$T_{min} = T_3 - (T_3 - T_4) \cos \left[\frac{2\pi}{365} (n - 25) \right] \tag{2.2}$$

Where T_{max} is the daily maximum temperature. T_{min} is the daily minimum temperature and n denotes the day of the year. T_1, T_2, T_3, T_4 values are constants which vary according to the cities. In this article, these constants are shown in Table 1 for the city of Istanbul.

Table 1. The constants of the temperature equations for Istanbul

T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)
18.3	8	3.7	11.3

According to these constants, the mean absolute error is ± 3 °C and the average standard error is ± 3.79 °C for T_{max} . The mean absolute error is ± 2.42 °C and the average standard error is ± 3.04 °C for T_{min} . For hourly the temperature values, the times which occur the minimum and the maximum temperatures during the day must have find.

$$t_{min} = 12 - (t_d / 2) \tag{2.3}$$

$$t_{max} = 12 + [t_{min} (12 - t_{min})] / 13.5 \tag{2.4}$$

$$t_d = (2 / 15) \text{ArcCos}[-\tan \phi \tan \delta] \tag{2.5}$$

Where t_d is the length of day. It depends on the declination angle and the latitude. The latitude of Istanbul is 40°. Declination angle equation is as follows.

$$\delta = 23.45 \text{Sin} \left[\frac{2\pi}{365} (n + 284) \right] \tag{2.6}$$

Hourly values of the temperature to reach day is divided into two periods.

For the first period ($t_{max} \geq t \geq t_{min}$):

$$T = T_{min} + (T_{max} - T_{min}) \left\{ \text{Sin} \left[\frac{\pi}{2} \left(\frac{t - t_{min}}{t_{max} - t_{min}} \right) \right] \right\}^{1.6} \tag{2.7}$$

For the second period ($t_{min} \geq t \geq t_{max}$):

$$T = T_{max} - (T_{max} - T_{min}) \left\{ \text{Sin} \left[\frac{\pi}{2} \left(\frac{t - t_{max}}{24 + t_{min} - t_{max}} \right) \right] \right\} \tag{2.8}$$

For example, the minimum and maximum temperatures for any one day are at 7.00 a.m. and 14.00 p.m. respectively.

The equation 2.7 is being used for finding the temperature values which are the remaining in between 7.00 a.m and 14.00 p.m. Equation 2.8 for the other hours is used. The daily of specific humidity values is founded with the help of the equations which are generated from the fifteen-year data.

$$w = w_1 + (w_0 - w_1) \{ \text{sin} [n - 25] \}^3 \tag{2.9}$$

The constants, w_0 and w_1 , for Istanbul are given below. According to these constants, the mean absolute error for specific humidity values is ± 1.26 gr/kg and the standard error of mean is ± 1.59 gr/kg.

Table 2. The constants of the humidity equations for Istanbul

w_1 (gr/kg)	w_0 (gr/kg)
4,2	13

The temperature values in every hour of the day using these equations are found for Istanbul. The histogram formed according to the temperature ranges is given in figure 1.

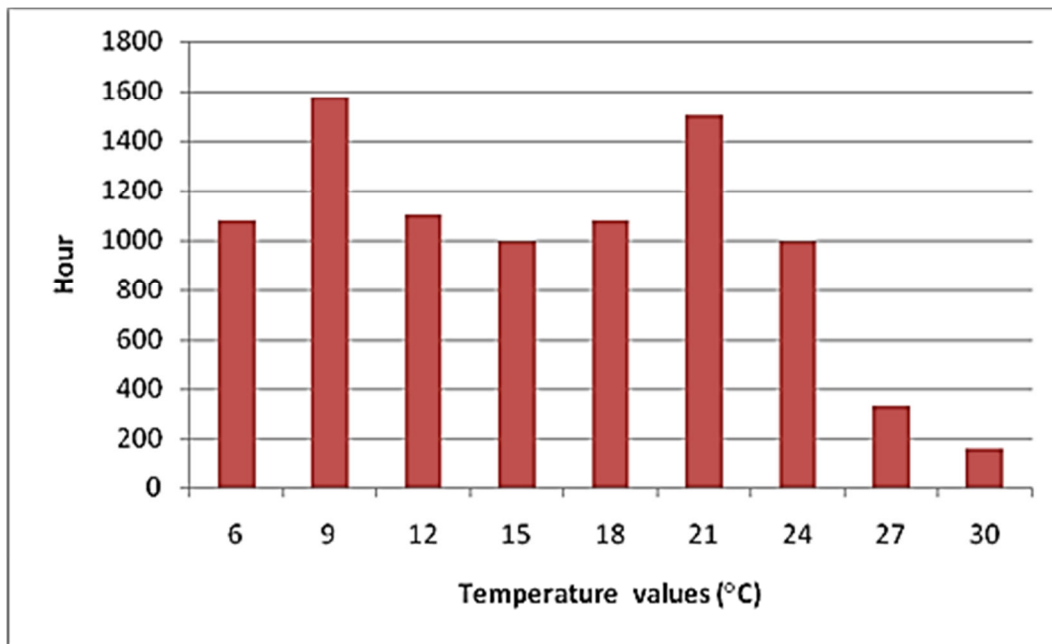


Figure 1. Temperature values for Istanbul

3. FREE COOLING APPLICATION FOR A FACTORY

For use in cooling the engine in a factory located in Istanbul, the group met a group of cold-water cooling needs. The operating conditions of the system for a cooling group are given in table 3.

Table 3. The operating conditions of the system for a cooling group

Operation	Value
Water inlet temperature	20 °C
Water exit temperature	30 °C
Volume flow rate for cooling water	15 m ³ /h

Cooling capacity from those given in the table;

$$Q_s = \dot{m} c_p \Delta T \tag{3.1}$$

In this system, the coefficient of performance of the air cooled chiller is chosen as 6. In this case, the energy consumed in the chiller is 29 kW. The system operates 24 hours a day and 365 days. In other words, the cooling time is 8760 hours. In this system, the cooling tower inlet temperature and outlet temperature are considered to be 25 and 20 °C respectively. When the difference approach between inlet and exit temperatures is accepted 5 °C and the wet-bulb temperature is lower than 15 °C in a cooling tower the chiller is off and the required cooling water can be obtained from cooling tower. This condition provided was determined that 5546 hours. The cooling fan power was regarded as 7 kW. In this case, coefficient of performance of the natural cooling is given as below.

$$COP_{nc} = \frac{174.16}{7} = 24.88$$

The sketch of the system with the free cooling is given in figure 2.

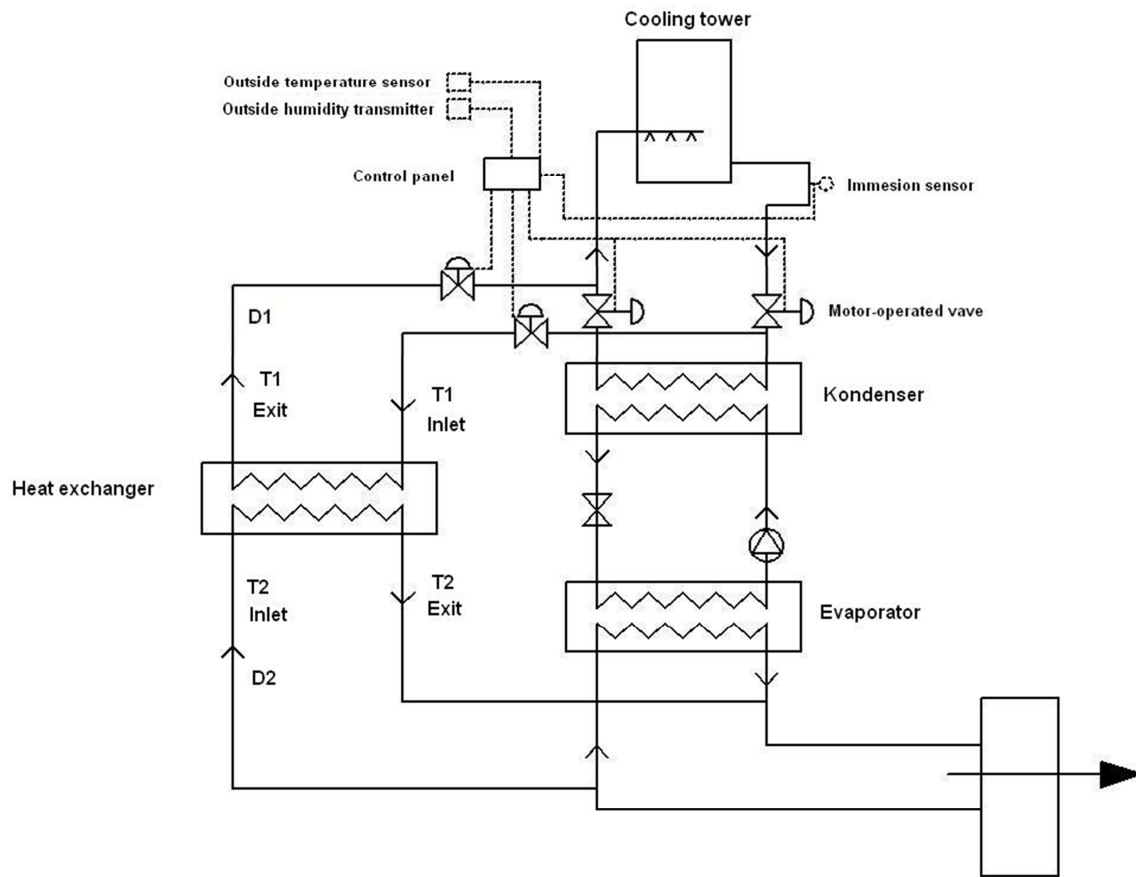


Figure 2. The sketch of the system with the free cooling

When the wet bulb temperature falls below 15 °C, the chiller is switched off and the free cooling is activated by using automatic control circuits in system. In this way, energy savings can be achieved. Both systems

used the same pumps, the energy consumption of pump did not participate in the savings accounts. Energy consumption is given in table 4.

Table 4. The compare of the default cooling and free cooling for an industrial process

	Chiller system	Free cooling system
Cooling capacity (kW)	174.17	174.17
COP	6.00	24.88
Energy consumption (kW)	29.03	7.00
Cooling time (h)	8760	5546
Total consumption energy (kWh)	254283.33	38822.00
Electricity unit price (\$/kWh)	0.09	
The total annual energy cost (\$/year)	22885.49	3493.98

The cooling group will work at hours that are not appropriate for free cooling within the year in this

system. Durations of free cooling according to months for Istanbul are given figure 3.

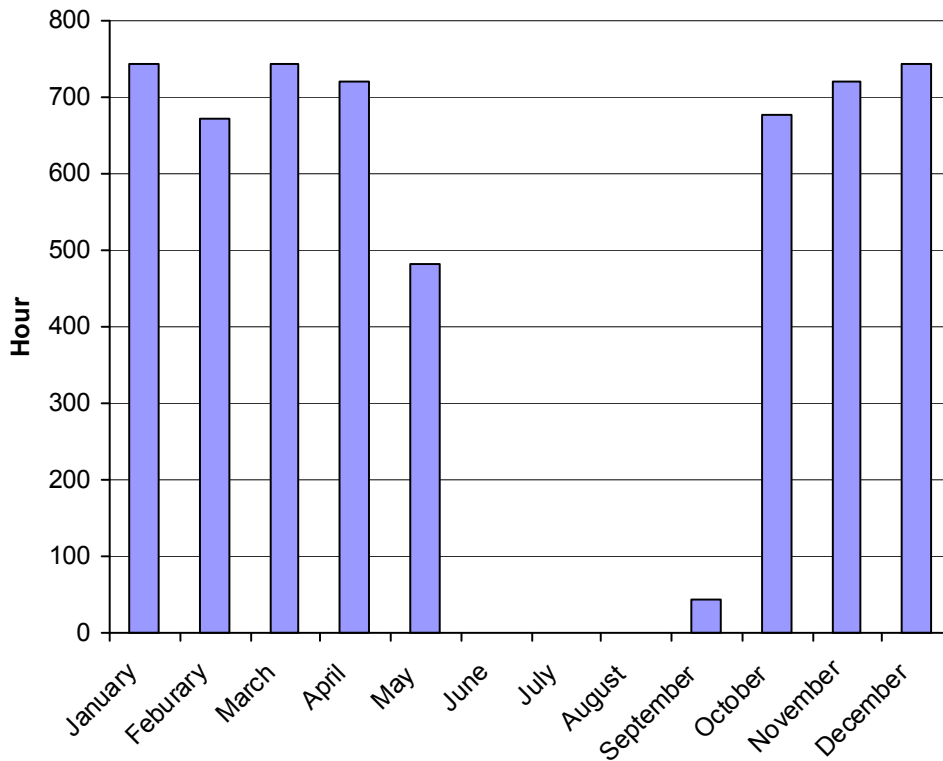


Figure 3. Durations of free cooling according to months for Istanbul

There are 3214 hours which are not appropriate for free cooling. The electricity consumption will be 93295.28 kWh at total in these hours.

3.1. Economic analysis

The savings amount of free cooling for an example of industrial process is given table 5.

Table 5. The savings amount of free cooling for an example of industrial process

	Only cooling group	Applied systems together
Total electricity consumption (kWh)	254283.33	132117.28
The total electricity cost (\$)	22885.4997	11890.5552
Annual earnings (\$/year)	-	10994.9445
The energy savings (kWh)	-	122166.06
Savings rate (%)	-	48.04

There are needed the automatic control elements for the establishment of the free cooling system. The control elements measure the external environment temperature and provide the opening and closing of valves automatically. Prices of the automatic control elements

vary according to pipe diameter. Because the cooling capacity is 174.17 kW, the cooling tower needs to take

this quantity heat from hot water. The water flow rate is 30 m³/h in a closed-loop cooling tower and the water velocity is assumed as 1.8 m/s. Therefore, the pipe diameter is determined as 76.8 mm. The pipe diameter

for standardization was chosen DN80 in this paper. The heat exchanger effectiveness is assumed as 0.7 for this system. So, the serpentine area is calculated as 20 m².

$$\varepsilon = \frac{q}{q_{\max}} \quad (3.2)$$

$$A = \frac{q}{k \cdot \Delta_{lm}} \quad (3.4)$$

Where k = 1500 W/m²K and $\Delta_{lm} = 4 \text{ } ^\circ\text{C}$

Equipment prices of free cooling system are given in table 6.

$$q = C_{\min} \cdot (T_{1,inlet} - T_{2,exit}) \quad (3.3)$$

Table 6. Equipment prices of free cooling system

Equipment type	Number	Unit price (\$)
Measurement Group	1	775
Butterfly valve (DN 80)	4	142
Butterfly-valve engine	1	118
Heat exchanger (20 m ²)	1	6315
The total cost (\$)	7776	

4. CONCLUSIONS

The free cooling application in cooling tower for an industrial plant located in Istanbul was investigated in this paper. The free cooling time was determined as 5546 hours after the calculation of the required climate data. As a result of calculations made for the application, when the cooling group together with free-cooling is applied to an industrial plant the electricity consumption decreases from 254283.33 to 132117.28 kW. Then the decreases rate is %48. Savings in electricity consumption is provided with a gain of \$ 10994.95. Installation cost of system is \$7776 and it pays for itself in less than a year. The free cooling application for industrial plants cooling processes using cooling tower gains both monetary and saving energy.

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