Chiller-Dry Cooler Basic Energy Analysis Based on Istanbul Bin Values

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Introduction

The plastics industry is one of the sectors where refrigeration applications are most needed. Therefore, the method to be used should be chosen consciously. Cooling of the molds used in production is especially important in terms of product quality. In cooling applications in the plastics industry, free cooling provides a significant reduction in energy consumption.

Air-cooled chillers used in the plastics industry, despite the ease of use and maintenance, operating costs are high. However, natural (free) cooling can be achieved by supplementing a year-round system with dry coolers. Energy can be used efficiently through free cooling systems decreasing cooling water temperatures below outdoor air temperature (Figure 1).

Figure 1. Chiller-dry cooler integration with horizontal and V type dry coolers.

The main purpose of the study is to make an overall economical assessment of the dry cooler integrated to a process chiller operating in Istanbul using annual bin values.

Assumptions

The operation of the dry cooler and the air cooled chiller was examined in the context of a scenario mentioned below. All assumptions and approaches in the calculation are as follows;

- The plant is accepted as a process water cooling system with $T_{cooling\ water\ supply}$ = 11°C, $T_{cooling\ water\ return}$ = 16°C.
- The system requires cooling for 20 hours / 365 days.
- The total cooling load is assumed to be 500 kW.
- Since the calculations are to determine the amount of energy efficiency by using the chiller and dry cooler together, the outside temperature range subject to comparison and calculation is -6°C / 18°C. Above 18°C, only the chiller operates.
- Bin values collected from meteorological data of Istanbul between 1989-2012 were used.
- Operating regions and scenarios were accepted as follows.

    - ***100% Mechanical Cooling Range*** - 100% chiller operation is required when the ambient air temperature is above the water return temperature. When $T_{ambient}$ > 14°C, it is entered into the mechanical cooling zone. The condenser fans and the compressor operate at 100% load. The dry cooler does not operate.

    - ***Load Sharing Range*** - 14°C ≥ $T_{ambient}$ ≥ 6°C is the zone where the chiller and dry cooler operate in load sharing mode. When the ambient air temperature drops below the return water temperature by at least 2°C ($T_{ambient}$ = 16°C - 2°C = 14°C), the dry cooler starts operating as a pre-cooler. Due to the decrease in the return water temperature sent to the chillers, the compressor load decreases proportionally. In the study, it is assumed that the chiller compressor has proportional capacity control and the appropriate compressor selection is made. However, in the calculation, the specific temperatures and the proportions corresponding to these temperatures were used for convenience. It should be considered that the gain calculated by the proportional control will be slightly higher. In addition, it is assumed that the dry cooler and condenser fans operate with step control.

- ***100% Dry Cooler Operating Range:*** Fully dry cooler operates at minimum 5°C below supply water temperature and lower temperatures ($T_{ambient} \leq 5°C$) of ambient air temperature. The chiller won't start. In this example, the system operates with 100% dry cooler (natural cooling) when the air temperature $T_{Cooling\ water\ supply}$ (11°C) - 5°C = 6°C and below.

Bin Values

In order to determine whether it is advantageous to apply natural cooling during the project phase and to make a proper investment decision, it is very important to know the annual repetition frequencies (bin values) and to evaluate these data (bin method) for any province. Bin values indicates how many hours a year the temperature values show up during certain time periods. Table 1 shows bin values for Istanbul for different time periods.

Table 1. Istanbul bin values

Temperature Intervals (t, °C)	Time Intervals (t, h)											
	0≤t<2	2≤t<4	4≤t<6	6≤t<8	8≤t<10	10≤t<12	12≤t<14	14≤t<16	16≤t<18	18≤t<20	20≤t<22	22≤t<24
-4 > t ≥ -6	2	2	4	3	1	0	0	0	1	2	0	2
-2 > t ≥ -4	10	9	7	11	6	4	4	4	3	3	6	9
-0 > t ≥ -2	11	14	14	14	12	11	8	13	21	19	17	13
2 > t ≥ 0	47	45	47	43	35	28	31	22	24	28	34	41
4 > t ≥ 2	43	54	58	45	35	33	19	28	39	44	45	40
6 > t ≥ 4	73	69	61	64	54	46	56	61	60	74	79	76
8 > t ≥ 6	55	60	69	56	59	53	54	51	56	49	40	52
10 > t ≥ 8	69	62	53	62	55	59	50	51	50	51	64	70
12 > t ≥ 10	56	53	66	59	62	50	47	41	52	60	59	54
14 > t ≥ 12	82	100	85	47	48	55	56	68	56	59	66	67
16 > t ≥ 14	47	39	40	58	48	48	50	47	51	60	57	64
18 > t ≥ 16	56	51	57	53	47	50	48	43	44	45	42	41
20 > t ≥ 18	63	76	72	56	61	61	54	49	50	50	60	61

As can be seen from Table 1, the temperature of 8°C-10°C in Istanbul was observed to be 59 hours during the year between 10.00-12.00. This value is the average of the meteorological data between the years of 1989-2012.

Dry Cooler and Chiller Load Sharing Scenario

Table 2 shows the energy values and capacity ratios that the dry cooler and the chiller will use to achieve the total cooling capacity in the -4°C/18°C temperature range. Using the unit price of electricity according to these energy values, the calculations of energy cost are given in the scenario of working with dry cooler and chiller for Istanbul.

Table 2 - 100% mechanical and dry cooler-chiller comparison for Istanbul

Istanbul Bin Values	17	76	167	425	483	644	654	696	659	789	609	577
Operating 20 hours/day	14	63	139	354	403	537	545	580	549	658	508	481
Temperature Range (°C)	**-6/-4**	**-4/-2**	**-2/0**	**0/2**	**2/4**	**4 / 6**	**6/8**	**8/10**	**10 /12**	**12/14**	**14/16**	**16/18**
100% MECHANICAL COOLING												
Energy Consumed (kWh)	35	40	46	50	54	58	69	69	69	69	69	69
Total Energy (KWh/Year)	496	2533	6402	17708	21735	31127	37714	40136	38002	45499	35119	33274
Hourly Energy Cost (€/kWh)	0,10 €											
Energy Cost (€)	50	253	640	1.771	2.174	3.113	3.771	4.014	3.800	4.550	3.512	3.327
Total Energy Cost (€)	**30.974 €**											
	DRY COOLER						***DRY COOLER/CHILLER***				***CHILLER***	
Energy Consumed (kWh)	0,72	1,08	1,08	1,44	1,80	1,80	15,64	35,50	49,04	62,73	69,20	69,20
Total Energy (KWh/Year)	10	68	150	510	725	966	8524	20590	26931	41245	35119	33274
Hourly Energy Cost (€/kWh)	0,10 €											
Energy Cost (€)	1	7	15	51	72	97	852	2.059	2.693	4.124	3.512	3.327
Total Energy Cost (€)	**16.811 €**											
	ENERGY SAVING (%)									**Annual Saving (Euro)**		
	46%									**14.163**		

In case of using an EC *(Electronically Commutated)* fan motor, additional improvements in terms of operating costs and return of investment times should not be overlooked. Due to the capacity control of the chiller in case of 100% mechanical cooling, energy consumption in the range of -6 / 6°C has been gradually reduced. It is useful to cooperate with Friterm technical sales department to make more realistic assessments to suit your business conditions.

Energy Calculations for Operating Scenarios

As shown in Table 2, when 100% mechanical cooling is performed, the chiller is activated in the 14/18°C temperature range and this temperature range is not suitable for natural (free) cooling. In the case of interoperability, the power consumed by the chiller and the dry cooler is calculated separately. In this case, it is seen that the total energy consumption is lower than the energy consumed in 100% mechanical cooling.

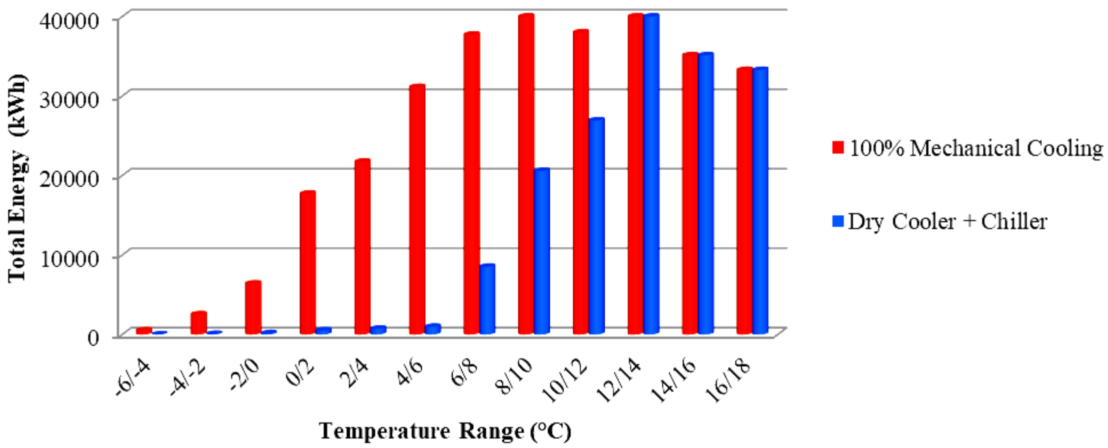

Figure 2 - Partial and free cooling energy values

In the partial and 100% free cooling zone, the energy consumed by the dry cooler is only fan power, and the fans turn off gradually as the outside temperature drops. In the winter, when the wind velocity

is high, the cooling effect increases with the wind effect even if not all fans are in operation. As a result, dry cooler efficiency and energy saving vary depending on outdoor temperatures.
In Istanbul, temperatures below -6°C are not observed all year round. The graph showing the amount of energy to be spent for Istanbul in case of partial cooling and 100% natural cooling is shown in Figure 3.

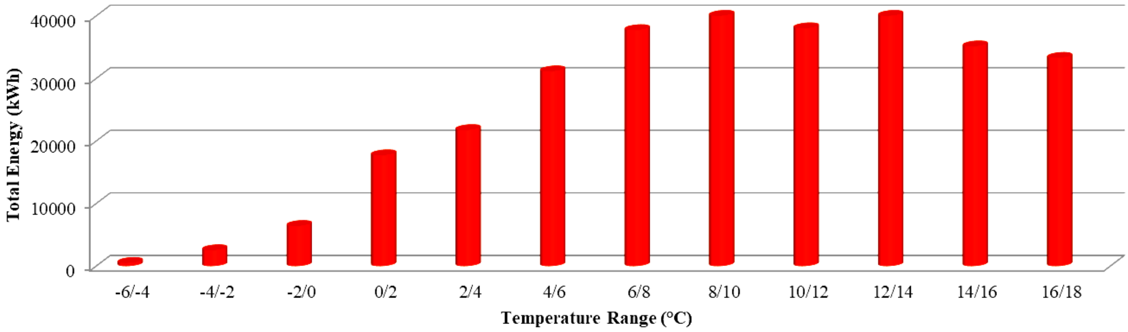

Figure 3 - Energy consumption based on bin values for Istanbul

Conclusion

Refrigeration is required for molding and oil circuits of the machines, cooling of the material after heat treatment, keeping the coating pools at certain temperatures in order to keep cutting and processing oils in the desired properties during summer as well as winter.

Energy costs were compared by selecting a dry cooler to meet the required cooling load for plants that use cooling water all year round and have an existing air-cooled chiller system. The meteorological conditions of the region where the cooling system is installed or to be installed, and the desired cooling water temperatures are the most crucial factors affecting the benefit that can be obtained from natural cooling.

Energy costs were calculated by using bin values in order to achieve partial free cooling when the outside air temperature drops 2°K and 6°K below cooling water temperature in 100% free cooling. An assessment based on dry coolers of different energy classes would be more realistic in order to clearly see the effect on efficiency, cost and return of investment times.

It can be noticed that dry coolers make an important contribution in terms of reducing operating costs and sustainable environment in industrial refrigeration plants with intensive energy consumption.

References

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