AN EXAMINATION ON FREE COOLING EFFICIENCY OF DRY COOLERS COMBINED WITH THE CHILLERS IN TANDEM WORK

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ABSTRACT

Increasing energy efficiency is one of the most important points in our era. Becoming a matter of primary importance in air conditioning, industrial, commercial and process cooling applications, energy efficiency affects designs of the systems included dry coolers and water chillers. Besides, legislations and restrictions on energy efficiency also urge manufacturers to develop high performance, energy efficient, environment friendly, economic and long life products. In these purposes, the tendency towards alternative energy efficient systems, which use natural resources, is increasing. Free cooling is one of the natural resourced methods for energy efficiency. This paper is intended to provide information on free cooling efficiency with a theoretically examination of A, C and E energy class dry coolers combined with the chillers in tandem work in air conditioning application.

1. INTRODUCTION

Heating is required in the buildings in Winter and Fall, whereas cooling is also be needed for some parts inside such as large computer and server rooms, internet and telecommunication data bases, conference rooms, some parts of shopping malls, crowded places, etc. These are the typical examples of places that require cooling also in winter.

As outside ambient temperatures drop below the required cooling water temperatures, free cooling systems can be used and considerable energy saving gained. The system of free cooling, which reduces operational costs with the increase in efficiency, entirely or partially eliminates the need for compressor work of the chiller at low ambient temperature periods. Dry cooler systems have an important function in energy efficiency, operating either with a chiller or independently according to application.

Free Cooling Systems can be grouped in two basic categories as *Air-Side Free Cooling* and *Water-side Free Cooling* systems. [1]: Free Cooling for *Air-Side* Cooling System Applications include reducing the costs of energy consumption via using directly the ambient air to cool the inner environment at low ambient temperatures. Free Cooling for *Water-Side* Cooling System Applications include reducing the costs of cold water production provided by chiller. Free cooling, employed in systems which require cooling water, obtains cooling water without operating or partially operating the chiller compressor by taking advantage of the low ambient temperature [1], [2].

Widely part of the products that are used in free cooling includes the finned block heat exchangers which can be applied in two ways that

1. Free Cooling Chillers (Integrated Free Cooling Coil) Applications
2. Dry Cooler Applications

These systems can be used as the ambient temperature drops 1.5 - 2.0°C below the required cooling water temperature. The working principle of the system can be defined by three different approaches as

1. 100% Mechanical Cooling (Chiller are in operation. No Free Cooling Application.)
2. Partially Free Cooling (Load sharing, Pre-cooling. When the ambient temperature falls below 1,5 -2.0 °C of the required cooling water temperature, the load can be shared between dry cooler and chiller compressor.)
3. 100% Free Cooling (Chiller compressor does not work. 100% Free cooling can be possible when the ambient temperature drops below at least 5 °C of the required cooling water.)

2. FREE COOLING CHILLERS (INTEGRATED FREE COOLING COIL) APPLICATIONS

In figure 1.A a photo, in figure 1.B a basic scheme of free cooling chiller is shown. The free cooling coil is placed in the front side of the air cooled condenser coil depending on the air flow direction of the unit. The control systems commands and directs the return water to the free cooling coil for pre-cooling or fully free cooling as the ambient temperature drops below required water temperature.

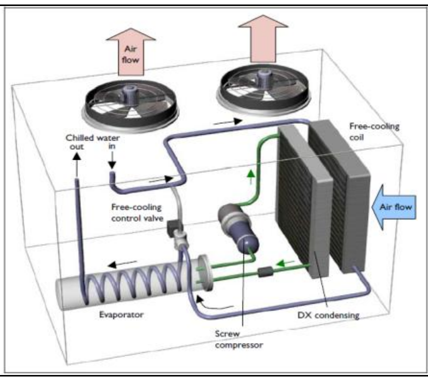


Figure 1.A Free Cooling Chiller [3]	**Figure 1.B** Scheme of Free Cooling Chiller [1]

3. DRY COOLER APPLICATIONS

Another finned block heat exchanger system used in cooling applications is called as Dry Cooler (fig 2). Dry Coolers have wide application area in air conditioning and process water cooling systems. The working principle is transferring the return water load to the air by the aid of finned heat exchanger and fans. In this system the fin surface of the exchanger is dry. Relatively there is no risk of corrosion on the fins. Besides, depletion of the cooling water and associated health risks (such as legionella bacteria) is also eliminated by the closed-loop working of the system.

Figure 2.A Horizontal Type Dry Cooler	**Figure 2.B** V Type Dry Cooler [4]	**Figure 2.C** Chiller and Dry Cooler Application in tandem work [5]

Cooling of the water temperature in the dry coolers depends on the ambient dry bulb temperature, thus they are called as dry coolers. By using the dry coolers, cooling of the water can be achieved approximately 5 ^{0}C over the ambient dry bulb temperature. To have lower temperatures wet-dry coolers are used. Dry coolers are preferred as free coolers for their energy saving advantages in computer and server rooms which require cooling for 24 hours, internet and telecommunication data centers, certain parts of shopping malls and business centers where energy is intensely used. Specially, the system provides huge savings during the night period.

4. A THEORETICALLY EXAMINATION ON FREE COOLING EFFICIENCY OF DRY COOLERS COMBINED WITH THE CHILLERS IN TANDEM WORK IN AIR CONDITIONING APPLICATION

In order to calculate energy efficiency, a scenario is scripted for the dry coolers which have A, C and E energy classes working in Ankara city, Turkey. Besides that, via using the same method, calculations are also made for other 79 cities located in different regions of Turkey and energy efficiency results are given in Table 5.

All of the scripted scenario assumptions are indicated below:

1. The place which requires cooling is assumed as a combined business and shopping center. Due to the intensive energy characteristics of the place, even in the Winter, Spring and Fall seasons cooling is required.
2. Cooling demand assumed for 16 hours/365 days.
3. The total cooling load is assumed to be fixed as 130 kW through the whole year. (For easy understanding of the calculations the effects of seasonal changes are neglected).
4. It is assumed that the cooling is made by the VAV devices which can respond to the variable cooling loads and ceiling type fan coils and packed-type AHUs in certain parts.
5. Cooling water regime is assumed as 12 °C / 16 °C.
6. The calculations and comparisons are taken below 16 °C as free cooling range.
7. Calculations and tables are made for Ankara city, Turkey. For other 79 cities located in different regions of Turkey the same calculation methods are applied.
8. The bin weather data for those cities are taken from Turkish State Meteorological Service (TSMS) sources [6].
9. Working conditions of scripted scenario is assumed as follows:

   - <u>100% Mechanical Cooling Temperature Zone:</u> When the ambient temperature is above the return water temperatures ($T_{ambient}$>= 15 °C), 100% mechanical cooling is required. Condenser fans and compressor is to work.

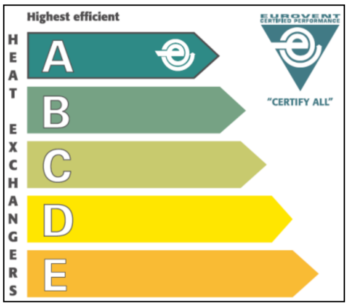
   - <u>Partial Free Cooling (Precooling/Load sharing) Temperature Zone:</u> As the ambient air temperature drops at least 2 °C below the return water temperature (16 °C -2°C =14 °C) , the dry cooler begins to function as the pre-cooler. Working condition is that ambient temperature ($T_{ambient}$) should be between 14 °C and 7 °C. Due to the decrease in the return water temperature which is sent to the water cooler group, compressor and condenser load displays a proportional decrease.

   - <u>100% Free Cooling Temperature Zone:</u> When the ambient temperature is at least 5 °C below cooling water temperature ($T_{ambient}$ <= (12 °C -5°C) 7 °C) only the dry cooler is in operation. Chiller is not running.

10. The compressor of chiller is assumed to be frequency controlled. However, for the ease of the calculations certain temperatures and the ratios are used. It should be also considered that the gain calculated via frequency control would higher than the given values. Besides, the dry cooler fans and the condenser fans are considered as step controlled.

11.In order to clearly indicate the effects of dry cooler energy efficiency levels on consumption and costs, calculations are made for 3 different energy efficiency classes as A class, C class and E class.

Additional information on Energy Efficiency Classes:



Dry cooler capacity standard is EN 1048 Heat Exchangers-Air Cooled Liquid Coolers "Dry Coolers"-Test Procedure for Establishing the Performance.

Energy efficiency levels are indicated in EUROVENT Rating Standard For Forced Convection Air Cooled Liquid Coolers "Dry Coolers" 7/C/003 – 2010 [7].

Table 1. Energy Efficiency Class [7]

Class	Energy Consumption	Energy Ratio (R)*
A	Extremely low	R > =110
B	Very low	70 =< R < 110
C	Low	45 =< R < 70
D	Medium	30 =< R < 45
E	High	R < 30

* The energy ratio "R" is obtained by dividing the *standard capacity* of the product by the total energy consumption of unit.

12.Tandem working scenario of Dry cooler and Chiller by temperature intervals is shown in Table 2 in which values are only for A energy efficiency class dry cooler. Values differ for C and E energy class dry cooler applications. Detailed calculation values for A, C and E class dry coolers are displayed in Table 3.

TABLE 2. TANDEM WORKING SCENARIO OF DRY COOLER AND CHILLER BY TEMPERATURE INTERVALS (ANKARA)

Repeated Temperature Frequency (hour/Year)	2	14	52	140	318	575	823	878	876	851	866	899
Frequency for 16 hours of working per day (hour/Year)	1,3	9,3	34,7	93,3	212,0	383,3	548,7	585,3	584,0	567,3	577,3	599,3
Temperature Interval (°C)	**-18/-15**	**-15/-12**	**-12/-9**	**-9/-6**	**-6/-3**	**-3/0**	**0 / 3**	**3 / 6**	**6 / 9** (7, 8, 9)	**9 /12** (10, 11, 12)	**12/15** (13, 14, 15)	**15/18**
Working Zone	100% Free Cooling 4 Fans Work			100% Free Cooling 6 Fans Work		100% Free Cooling 8 Fans Work		100 % Free Cooling 10 Fans Work	%20 MC (4 Fans) / 80% Free Cooling (10 Fans)	% 45 Mechanical Cooling (6 Fans) / 55% Free Cooling (10 Fans)	% 72 Mechanical Cooling (8 Fans) / %28 FC (10 Fans) (13, 14)	% 100 Mechanical Cooling Zone (8 Fans) (15; 15/18)
	%100 Free Cooling Side								Partially Free Cooling Side			

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Notes for Table2:

1. Temperatures used for partial side load and energy consumption calculations are 8,5 °C for 6 / 9°C interval; 11 °C for 9 / 12°C interval; 13,5 °C for 12 / 15°C interval. By pre-cooling of dry cooler (in proportional controlled load) the load that compressor is subjected are %20, %45 and %72 respectively.
2. As ambient air temperature decreases chiller and dry cooler fans are step controlly stopped and the consumption of the fans decrease. (The temperatures determined for the step control of the fans differ approximately 1-2 ^{0}C than the indicated temperature intervals in the real conditions, the meteorological temperature intervals are accepted as main intervals for the easy calculations.)

13. Capacity, load sharing and energy consumption values of the dry cooler and the chiller are given in the Table 3.A in accordance with the certain temperatures. Values are only for A energy efficiency class dry cooler. (Please also see detailed explanations for Tables 3A and 3B below.)

TABLE 3A. DRY COOLER AND CHILLER CAPACITY, POWER AND LOAD SHARING RATIOS

Working Zone	Ambient Temperature intervals (°C)	Dry Cooler Capacity (kW)	Dry Cooler Power (kW)	*Dry Cooler Capacity / Power Ratio*	Dry Cooler Load (%)	Compressor Capacity (kW)	Compressor power (kW)	*Compressor Capacity / Power Ratio*	Compressor Load (%)	Condenser Fan Power (kW)	Total Power of the Cooling Group (kW)	Dry Cooler+ Chiller Power (kW)	Total Cooling Capacity of the system(kW)
%100 Mechanical Cooling	Above 15°C	0	0,00	*0,0*	0,0%	132,1	17,3	*7,6*	100,0%	6,24	23,54	**23,54**	**132,1**
Partial Cooling	13-14°C	36,21	2,00	*18,1*	27,4%	96,3	12,2	*7,9*	72,9%	6,24	18,44	**20,44**	**132,51**
	(9/12) 10-11-12°C	72,7	2,00	*36,4*	55,0%	60,2	8	*7,5*	45,6%	4,68	12,68	**14,68**	**132,9**
	8-9°C	109,5	2,00	*54,8*	82,9%	26,4	3,46	*7,6*	20,0%	3,12	6,58	**8,58**	**135,9**
% 100 Free Cooling	3 / 7°C	132,1	2,00	*66,1*	100,0%	0	0	-	0,0%	0	0,00	**2,00**	**132,1**
	0 / 3°C	132,1	1,60	*82,6*	100,0%	0	0	-	0,0%	0	0,00	**1,60**	**132,1**
	-3 / 0°C	132,1	1,60	*82,6*	100,0%	0	0	-	0,0%	0	0,00	**1,60**	**132,1**
	-6 / -3°C	132,1	1,20	*110,1*	100,0%	0	0	-	0,0%	0	0,00	**1,20**	**132,1**
	-9 / -6°C	132,1	1,20	*110,1*	100,0%	0	0	-	0,0%	0	0,00	**1,20**	**132,1**
	-12 / -9°C	132,1	0,80	*165,1*	100,0%	0	0	-	0,0%	0	0,00	**0,80**	**132,1**
	-15 / -12°C	132,1	0,80	*165,1*	100,0%	0	0	-	0,0%	0	0,00	**0,80**	**132,1**
	-18 / -15°C	132,1	0,80	*165,1*	100,0%	0	0	-	0,0%	0	0,00	**0,80**	**132,1**

14. Energy consumption calculations of A, C and E class dry coolers and chiller (according to scenarios) are given in Table 3B which is calculation table for energy consumption values of both Tables 2.A and Table 4.

TABLE 3B. POWER CALCULATIONS FOR THE WORKING SCENERIOS

Temperature Interval (°C)	-18/-15	-15/-12	-12/-9	-9/-6	-6/-3	-3/0	0 / 3	3 / 6	6 / 9 (7, 8, 9)	9 /12 (10, 11, 12)	12/15 (13, 14, 15)	15/18
POWER CALCULATION FOR CHILLER IN %100 MECHANICAL COOLING SCENERIO												
Compressor Power (%100) (kw) *	14,83								14,83	15,61	16,44	17,30
Fan Power (kw) *	3,12								3,12	4,68	6,24	6,24
Chiller Power (kw)	**17,95**								**17,95**	**20,29**	**22,68**	**23,54**
* As ambient temperature decreases, compressor efficiency increases and condenser fans are stopped as in step control.												
POWER CALCULATIONS FOR CHILLER IN PARTIALLY COOLING SCENERIO												
Compressor Power (%100) (kw) *	0,00								3,46	8,00	12,20	-
Fan Power (kw) *	0,00								3,12	4,68	6,24	-
Chiller Power (kw)	**0,00**								**6,58**	**12,68**	**18,44**	**0,00**
POWER CALCULATIONS FOR "A CLASS" DRY COOLER IN %100 FREE COOLING AND PARTIAL COOLING SCENERIOS												
Fan Power(kw) **	0,80	0,80	0,80	1,20	1,20	1,60	1,60	2,00	2,00	2,00	2,00	0,00
**As ambient air temperature decreases chiller and dry cooler fans are step controlly stopped and the consumption of the fans decrease. (The temperatures determined for the step control of the fans differ approximately 1-2 ^{0}C than the indicated temperature intervals in the real conditions, the meteorological temperature intervals are accepted as main intervals for the easy calculations.)												
TOTAL POWER CALCULATIONS FOR A CLASS DRY COOLER AND CHILLER IN PARTIALLY COOLING												
Total Power (kw)	**0,80**	**0,80**	**0,80**	**1,20**	**1,20**	**1,60**	**1,60**	**2,00**	**8,58**	**14,68**	**20,44**	**0,00**
POWER CALCULATIONS FOR "C CLASS" DRY COOLER IN %100 FREE COOLING AND PARTIALLY COOLING SCENERIOS												
Fan Power (kw) **	1,32	1,32	1,98	1,98	2,64	2,64	3,30	3,96	3,96	3,96	3,96	0,00
**As ambient air temperature decreases chiller and dry cooler fans are step controlly stopped and the consumption of the fans decrease.												
TOTAL POWER CALCULATIONS FOR C CLASS DRY COOLER AND CHILLER IN PARTIALLY COOLING												
Total Power (kw)	**1,32**	**1,32**	**1,98**	**1,98**	**2,64**	**2,64**	**3,30**	**3,96**	**10,54**	**16,64**	**22,68**	**0,00**
												Inefficient in this zone. Thus 100% Mechanical cooling.
POWER CALCULATIONS FOR "E CLASS" DRY COOLER IN %100 FREE COOLING AND PARTIALLY COOLING SCENERIOS												
Fan Power (kw) **	4,00	4,00	4,00	6,00	6,00	8,00	8,00	10,00	10,00	10,00	10,00	0,00
**As ambient air temperature decreases chiller and dry cooler fans are step controlly stopped and the consumption of the fans decrease.												
TOTAL POWER CALCULATIONS FOR E CLASS DRY COOLER AND CHILLER IN PARTIALLY COOLING												
Total Power (kw)	**4,00**	**4,00**	**4,00**	**6,00**	**6,00**	**8,00**	**8,00**	**10,00**	**17,95**	**20,29**	**22,68**	**0,00**
Under these conditions E class product can only be used in 100% free cooling zone.									Under these conditions E class product is not efficient. Thus, 100% mechanical cooling is applied.			

Notes for Table 3A and 3B:

1. As A class dry cooler FRITERM FYKS 80 25 D 4 2,5 D E (10 fans) model; as C class dry cooler FRITERM FYKS 63 26 D 4 3,2 L (12 fans) model; as E class dry cooler FRITERM FYKS 80 15 D 3 2,5 S (5 fans) model selected [4].
2. The compressor is selected frequency controlled RC2-100B Screwed Compressor [8].
3. Condenser is selected as air cooled FRITERM FUH YK 63 24 C 1 2,5 S model.
4. The calculations for the capacity performance in different ambient temperatures are done with the constant flow-rate assumption in dry coolers.
5. Calculation interval is assumed between -18/-15°C and +18/+15°C.
6. Pumping power is not taken into account in comparison calculations.
7. The values above are found via using the producer firms’ product selection programs.

15. In Table 4, energy saving calculations are given only for Ankara city. Please see Table 5 for energy efficiency of other 79 cities located in different regions of Turkey.

TABLE 4. BENEFIT CALCULATION OF TANDEM WORKING SCENERIO(ANKARA)																
Repeated Temperature Frequency (hour/Year)	**2**	**14**	**52**	**140**	**318**	**575**	**823**	**878**	**876**			**851**	**866**			**899**
Frequency for 16 hours of working per day (hour/Year)	**1,3**	**9,3**	**34,7**	**93,3**	**212,0**	**383,3**	**548,7**	**585,3**	**584,0**			**567,3**	**577,3**			**599,333**
Temperature Interval (°C)	**-18/-15**	**-15/-12**	**-12/-9**	**-9/-6**	**-6/-3**	**-3/0**	**0 / 3**	**3 / 6**	**6 / 9**			**9 /12**	**12/15**			**15/18**
									7	**8**	**9**		**13**	**14**	**15**	
%100 MECHANICAL COOLING																
Energy Consumed (kW/h)	17,95	17,95	17,95	17,95	17,95	17,95	17,95	17,95	17,95	17,95	17,95	20,29	22,68	22,68	23,54	23,54
Energy Consumed in Total (kW)	23,9	167,5	622,3	1675,3	3805,4	6880,8	9848,6	10506,7	3494,3	3494,3	3494,3	11511,2	4364,6	4364,6	-	-
Energy cost per hour(€/kWh)	0,09 €															
Cost of Consumed Energy (€)	2 €	15 €	56 €	151 €	342 €	619 €	886 €	946 €	314 €	314 €	314 €	1.036 €	393 €	393 €	-	-
Total Cost of Consumed Energy (€)	**5.783 €**															
PARTIALLY FREE COOLING: COMPARISON WITH "A CLASS" DRY COOLER																
Energy Consumed (kW/h)	0,8	0,8	0,8	1,2	1,2	1,6	1,6	2	2	8,58	8,58	14,68	20,44	20,44	-	-
Energy Consumed in Total (kW)	1,1	7,5	27,7	112,0	254,4	613,3	877,9	1170,7	1670,2	1670,2	1670,2	8328,5	3933,6	3933,6	-	-
Cost of Consumed Energy (€)	0 €	1 €	2 €	10 €	23 €	55 €	79 €	105 €	150 €	150 €	150 €	750 €	354 €	354 €	-	-
Total Cost of Consumed Energy (€)	2.184 €															
CALCULATIONS	**ANNUAL SAVING (EURO)**						**EFFICIENCY (%)**						**RETURN OF THE INVESTMENT (YEAR)**			
	3.598 €						**62,23%**						**3,6**			
PARTIALLY FREE COOLING: COMPARISON WITH "C CLASS" DRY COOLER																
Energy Consumed (kW/h)	1,98	1,98	1,98	2,64	2,64	3,3	3,96	3,96	3,96	10,54	10,54	16,64	22,68	22,68	23,54	23,54
Energy Consumed in Total (kW)	2,6	18,5	68,6	246,4	559,7	1265,0	2172,7	2317,9	2051,8	2051,8	2051,8	9440,4	4364,6	4364,6	-	-
Cost of Consumed Energy (€)	0 €	2 €	6 €	22 €	50 €	114 €	196 €	209 €	185 €	185 €	185 €	850 €	393 €	393 €	-	-
Total Cost of Consumed Energy (€)	2.788 €															
CALCULATIONS	**ANNUAL SAVING (EURO)**						**EFFICIENCY (%)**						**RETURN OF THE INVESTMENT (YEAR)**			
	2.995 €						**51,79%**						**4,1**			
PARTIALLY FREE COOLING: COMPARISON WITH "E CLASS" DRY COOLER																
Energy Consumed (kW/h)	4	4	4	6	6	8	8	10	10	17,95	17,95	20,29	22,68	22,68	23,54	23,54
Energy Consumed in Total (kW)	5,3	37,3	138,7	560,0	1272,0	3066,7	4389,3	5853,3	3494,3	3494,3	3494,3	11511,2	4364,6	4364,6	-	-
Cost of Consumed Energy (€)	0 €	3 €	12 €	50 €	114 €	276 €	395 €	527 €	314 €	314 €	314 €	1.036 €	393 €	393 €	-	-
Total Cost of Consumed Energy (€)	4.144 €															
CALCULATIONS	**ANNUAL SAVING (EURO)**						**EFFICIENCY (%)**						**RETURN OF THE INVESTMENT (YEAR)**			
	1.639 €						**28,34%**						**5,5**			

TABLE 5. ENERGY SAVINGS IN 79 CITIES OF TURKEY FOR A, C AND E CLASS DRY COOLER																
Cities		Repeated Temperature Frequency (hour/Year)												Energy Saving (%)		
Temperature Intervals (◦C)		-18/-15	-15/-12	-12/-9	-9/-6	-6/-3	-3/0	-3 / 0	3 / 6	6 / 9	9 /12	12/15	15/18	A class	C class	E class
1	*Erzurum*	176	246	332	461	601	712	849	772	811	789	712	630	**71%**	**61%**	**39%**
2	Hakkari	29	88	203	359	599	794	831	659	616	661	630	704	**70%**	**60%**	**39%**
3	Ardahan	234	333	435	530	623	724	757	793	902	923	760	590	**70%**	**60%**	**39%**
4	Ağrı	170	213	290	373	572	678	786	671	695	774	728	663	**69%**	**60%**	**38%**
5	Kars	202	285	411	504	596	691	775	746	839	900	824	651	**69%**	**59%**	**38%**
6	Muş	116	167	233	294	485	683	826	585	631	693	709	695	**69%**	**59%**	**37%**
7	Bitlis	13	42	114	252	474	858	1085	788	734	795	770	689	**68%**	**57%**	**35%**
9	*Van*	22	70	149	287	470	748	941	827	781	803	785	802	**67%**	**57%**	**34%**
8	Bayburt	102	186	300	433	577	728	843	805	887	978	881	694	**67%**	**57%**	**34%**
10	Bingöl	21	48	98	198	368	639	917	768	722	704	682	696	**67%**	**56%**	**33%**
12	Tunceli	21	42	85	175	300	534	911	791	743	710	694	691	**66%**	**55%**	**33%**
11	Iğdır	22	48	104	207	440	723	691	649	661	724	740	787	**66%**	**55%**	**33%**
13	Erzincan	29	61	131	253	425	639	781	787	812	820	795	812	**65%**	**55%**	**32%**
15	Elazığ	3	16	53	136	305	573	836	837	787	750	692	705	**65%**	**54%**	**32%**
14	Sivas	54	98	178	292	460	658	865	844	859	934	947	808	**64%**	**54%**	**32%**
16	Yozgat	17	52	122	272	467	680	940	930	894	928	984	838	**64%**	**54%**	**31%**
18	Çankırı	8	22	60	167	358	659	943	874	826	831	869	867	**64%**	**54%**	**30%**
17	*Konya*	9	33	76	169	373	643	796	847	843	808	808	835	**64%**	**54%**	**30%**
19	Kayseri	28	61	121	237	416	680	804	804	864	907	886	780	**64%**	**53%**	**30%**
21	Malatya	0	4	32	103	253	540	795	833	792	728	693	715	**63%**	**53%**	**30%**
20	Gümüşhane	20	47	113	261	475	702	859	846	890	946	995	940	**63%**	**53%**	**30%**
22	Kastamonu	2	17	55	133	378	802	1034	940	903	965	996	866	**63%**	**53%**	**30%**
23	Eskişehir	2	12	52	168	365	708	870	887	904	876	920	886	**63%**	**53%**	**29%**
24	Kırşehir	13	39	83	182	347	579	824	825	847	872	861	903	**63%**	**52%**	**29%**
25	Çorum	8	16	55	153	348	664	950	899	918	948	943	862	**62%**	**52%**	**29%**
26	Kırıkkale	5	12	33	118	278	561	833	885	842	823	826	890	**62%**	**52%**	**28%**
28	*Ankara*	2	14	52	140	318	575	823	878	876	851	866	899	**62%**	**52%**	**28%**
27	Nevşehir	11	35	95	224	372	545	807	959	937	954	946	866	**62%**	**52%**	**28%**
29	Niğde	20	42	97	198	341	586	776	814	879	912	919	907	**62%**	**52%**	**28%**
30	*Afyon*	2	13	63	149	332	598	797	917	947	916	924	893	**62%**	**51%**	**28%**
31	Kütahya	2	13	45	144	343	652	822	937	969	968	976	926	**61%**	**51%**	**27%**
32	Aksaray	9	29	73	159	283	511	753	793	892	883	881	896	**61%**	**50%**	**27%**
33	Karaman	17	36	70	162	336	520	654	811	914	907	874	881	**61%**	**50%**	**27%**
34	*Isparta*	0	2	20	86	240	528	802	939	1078	975	844	833	**60%**	**50%**	**26%**
35	*Diyarbakır*	4	9	25	64	177	379	666	787	864	797	701	650	**60%**	**49%**	**26%**
36	Bolu	3	20	45	105	275	667	925	901	985	1061	1090	946	**60%**	**49%**	**25%**
37	Uşak	0	0	7	50	186	423	748	981	1065	940	873	876	**59%**	**48%**	**24%**
38	*Edirne*	0	2	13	55	166	414	749	880	871	864	886	961	**59%**	**48%**	**24%**
39	Siirt	0	1	10	30	79	281	670	869	890	782	685	644	**59%**	**48%**	**24%**

TABLE 5. ENERGY SAVINGS IN 79 CITIES OF TURKEY FOR A, C AND E CLASS DRY COOLER

Cities		Repeated Temperature Frequency (hour/Year)												Energy Saving (%)		
Temperature Intervals (◦C)		**-18/-15**	**-15/-12**	**-12/-9**	**-9/-6**	**-6/-3**	**-3/0**	**-3 / 0**	**3 / 6**	**6 / 9**	**9 /12**	**12/15**	**15/18**	**A Sınıfı**	**C Sınıfı**	**E Sınıfı**
40	*Mardin*	0	0	1	19	99	297	613	881	870	798	664	620	**59%**	**48%**	**24%**
41	Burdur	0	0	4	52	176	406	689	949	1077	935	841	867	**58%**	**48%**	**24%**
42	Bilecik	0	0	3	26	174	491	811	904	923	936	975	1088	**58%**	**48%**	**23%**
43	Amasya	2	4	8	36	147	428	751	874	887	888	903	987	**58%**	**48%**	**23%**
44	*Artvin*	0	0	2	30	159	477	846	915	892	929	1037	1231	**58%**	**47%**	**23%**
45	*G.Antep*	0	0	2	20	84	294	638	920	958	857	738	705	**58%**	**47%**	**22%**
46	Tokat	3	7	21	71	209	476	767	807	885	1003	1019	1028	**57%**	**47%**	**22%**
47	Kırklareli	0	1	9	55	140	359	770	883	905	964	938	963	**57%**	**47%**	**22%**
48	Karabük	0	0	0	10	109	381	750	948	965	934	1054	1085	**56%**	**46%**	**22%**
49	Batman	0	5	20	34	96	273	540	755	871	847	756	705	**56%**	**45%**	**21%**
50	Bartın	0	0	3	15	74	336	725	969	1112	1034	1063	1050	**55%**	**44%**	**20%**
51	Balıkesir	0	0	1	12	68	251	572	825	1013	972	932	909	**53%**	**43%**	**20%**
52	Adıyaman	0	0	0	6	40	151	464	811	971	887	737	687	**53%**	**43%**	**18%**
53	*Bursa*	0	0	2	5	36	237	568	810	1028	981	942	985	**53%**	**42%**	**18%**
54	Kahramanmaraş	0	0	0	3	30	155	420	775	977	925	788	708	**52%**	**41%**	**17%**
55	Tekirdağ	0	0	1	14	60	183	498	893	1074	1084	969	1002	**52%**	**41%**	**17%**
57	Adapazarı	0	0	0	2	22	152	545	886	1053	977	1035	1090	**51%**	**41%**	**17%**
56	Muğla	0	0	0	4	47	220	487	781	1153	1113	868	805	**51%**	**41%**	**16%**
58	Zonguldak	0	0	0	0	12	122	505	1018	1024	989	1120	1228	**51%**	**41%**	**16%**
59	Kocaeli	0	0	0	1	14	115	502	852	1025	978	994	1097	**51%**	**40%**	**16%**
60	Şanlıurfa	0	0	0	2	23	99	323	687	951	902	749	657	**50%**	**39%**	**16%**
61	*Denizli*	0	0	0	3	31	171	418	684	930	1023	923	848	**49%**	**39%**	**16%**
62	*İstanbul*	0	0	0	0	15	95	389	913	1144	1090	1025	983	**49%**	**39%**	**15%**
63	Kilis	0	0	0	0	12	80	298	713	1059	976	794	733	**49%**	**38%**	**14%**
64	Manisa	0	0	0	0	13	137	363	668	932	973	899	858	**49%**	**38%**	**14%**
65	Yalova	0	0	0	0	8	88	398	836	1088	1091	1042	1095	**48%**	**38%**	**14%**
66	*Çanakkale*	0	0	0	1	27	152	405	738	981	1048	1126	1017	**48%**	**37%**	**14%**
67	*Samsun*	0	0	0	0	9	68	350	836	1177	1104	1087	1134	**47%**	**37%**	**13%**
68	Rize	0	0	0	0	3	52	392	820	1178	1155	1067	1114	**47%**	**37%**	**13%**
69	Ordu	0	0	0	0	3	63	358	811	1221	1154	1089	1099	**47%**	**36%**	**13%**
70	Sinop	0	0	0	0	4	48	287	845	1357	1153	1074	1080	**47%**	**36%**	**12%**
71	*Trabzon*	0	0	0	0	6	54	286	788	1205	1095	1044	1141	**47%**	**36%**	**12%**
72	Giresun	0	0	0	0	0	42	290	785	1252	1114	1085	1123	**46%**	**36%**	**12%**
73	Aydın	0	0	0	0	2	59	245	478	810	1066	1082	995	**42%**	**31%**	**10%**
74	Antakya	0	0	0	0	2	35	160	362	736	1055	992	918	**39%**	**29%**	**8%**
75	*İzmir*	0	0	0	0	0	25	162	440	749	1056	1142	990	**39%**	**29%**	**8%**
76	*Antalya*	0	0	0	0	0	6	103	336	755	1080	1113	1138	**36%**	**26%**	**6%**
77	Adana	0	0	0	0	0	12	71	274	635	1024	1023	986	**35%**	**25%**	**6%**
78	Mersin	0	0	0	0	0	2	42	170	480	943	1108	1148	**31%**	**21%**	**4%**
79	İskenderun	0	0	0	0	0	0	8	78	311	809	1232	1258	**25%**	**15%**	**2%**

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