



Improving Chiller Efficiency

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Introduction

Air-conditioning systems account for 40 to 60% of the total electrical power consumption in buildings, depending on the load profile, location and duty conditions. The hybrid plant considered in this article has three water cooled chillers of 500 TR each with open type compressors, plus a 500 TR tandem type water cooled chiller with four compressors (all compressors being of equal capacity). All the chillers operate with R-22. For water cooled chillers with constant flow rate, out of the many factors I have analyzed, one stands out in my view: Entering Condenser Water Temperature (ECWT). This must be kept as low as possible for achieving better system performance. We are aware that the lower the ECWT, the lower will be the kW per TR produced by the chiller. But caution must be exercised while doing this on different types of chillers, namely open type, semi-hermetic and hermetic compressor systems. Unless an analysis is made and recorded, we would not be in a position to appreciate the effect of lower ECWT.

Relation Between ECWT and kW/TR

Out of sheer passion, at this hybrid plant, the above exercise was done on the 500 TR open type compressor screw chillers. *Table 1* and *Chart 1* show the effect of lower ECWT on kW/TR

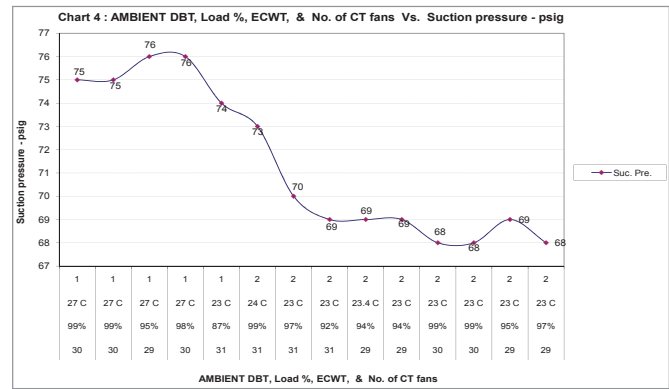
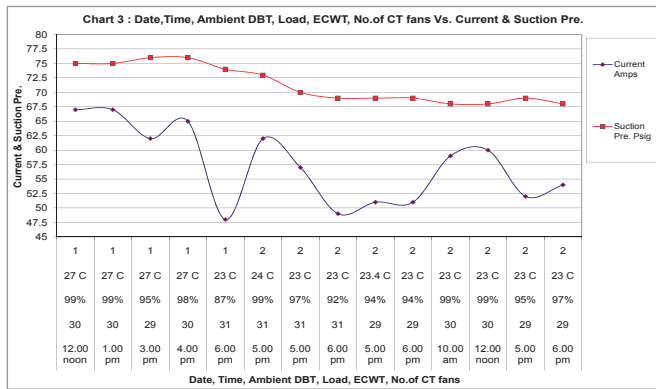
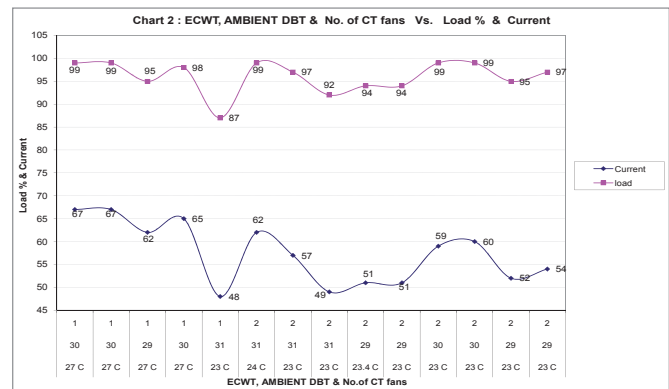
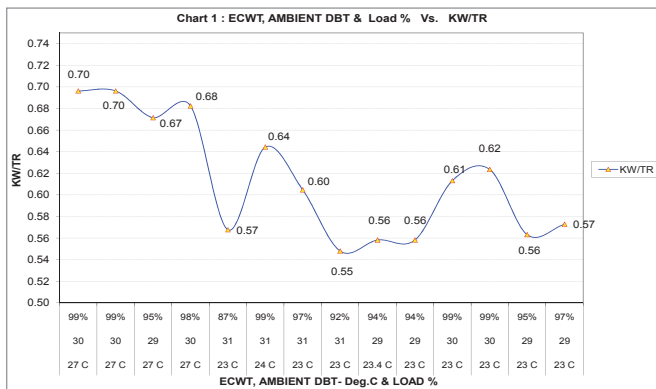
of the chiller. The manufacturer of the chillers was consulted on the above. It was informed that for open type compressor chillers, ECWT as low as 15.6°C (60°F) may be possible during winter season in India. This is because the lubricating oil follows a short path: compressor --> oil separator --> oil pump and back to compressor. The oil level at the oil separator sight glass should not be less than half (required for proper lubrication of the compressor). Hence, cooling tower is not required to be operated when temperatures are below 16°C. I understand that Carrier and McQuay centrifugal chillers with VFD can operate with minimum ECWT of 18°C (65°F) without the need for cooling tower cycling. For multi-compressor chillers provided with hermetic compressors, ECWT should not be less than 25°C and the discharge pressure should be maintained between 170 psig and 190 psig for better system performance. For hermetic compressor chillers this is very important, since the lubricating oil follows a longer path: compressor --> condenser --> evaporator and back to compressor. Hence only when, the discharge pressure is maintained, oil return to the compressor

About the Author

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Table 1: Effect of ECWT on current, kW/TR, seal oil temp. suction and Discharge pressures

Date	Time	Atm. temp. Deg.C	Current amps.	load	Suc.	Disc.	Cooler			Condenser			No. of CT fans	kW	TR	kW per TR	Seal oil temp.		Atm. temp. Deg.C
					Pre.	Pre.	ECHWT	LCHWT	Diff.	ECWT	LCWT	Diff.					Deg.F	Deg.C	
					psig	psig	Deg.C			Deg.C									
10-Sep-04	12.00 noon	30	67	99%	75	197	9.2	5.2	4	27	32	5	1	344.7	495	0.70	112	44.4	30
10-Sep-04	1.00 pm	30	67	99%	75	197	9.3	5.5	3.8	27	32	5	1	344.7	495	0.70	113	45.0	30
10-Sep-04	3.00 pm	29	62	95%	76	194	8.6	5	3.6	27	33	6	1	318.9	475	0.67	115	46.1	29
10-Sep-04	4.00 pm	30	65	98%	76	197	9.1	5.3	3.8	27	32	5	1	334.4	490	0.68	113	45.0	30
10-Sep-04	6.00 pm	31	48	87%	74	170	8	4.9	3.1	23	27	4	1	246.9	435	0.57	107	41.7	31
10-Sep-04	5.00 pm	31	62	99%	73	182	9	5	4	24	29	5	2	318.9	495	0.64	109	42.8	31
13-Sep-04	5.00 pm	31	57	97%	70	175	8.6	5	3.6	23	29	6	2	293.2	485	0.60	106	41.1	31
13-Sep-04	6.00 pm	31	49	92%	69	160	8.4	5	3.4	23	28	5	2	252.1	460	0.55	102	38.9	31
14-Sep-04	5.00 pm	29	51	94%	69	160	8.5	5.3	3.2	23.4	27.5	4.1	2	262.4	470	0.56	101	38.3	29
14-Sep-04	6.00 pm	29	51	94%	69	159	8.7	5.1	3.6	23	27	4	2	262.4	470	0.56	100	37.8	29
15-Sep-04	10.00 am	30	59	99%	68	169	9.4	5.2	4.2	23	29	6	2	303.5	495	0.61	103	39.4	30
15-Sep-04	12.00 noon	30	60	99%	68	170	9.6	5.3	4.3	23	29	6	2	308.7	495	0.62	103	39.4	30
15-Sep-04	5.00 pm	29	52	95%	69	163	9.1	5.4	3.7	23	28	5	2	267.5	475	0.56	102	38.9	29
15-Sep-04	6.00 pm	29	54	97%	68	166	8.8	5	3.8	23	29	6	2	277.8	485	0.57	103	39.4	29



would be adequate. Otherwise, the oil will start collecting at the flooded cooler and the compressor would trip on low oil level.

Advantages of Lower ECWT

The advantages of lower ECWT are many, and the following would give some idea to the readers.

1. Chillers designed for higher ECWT than normal summer conditions would consume lesser kW/TR, when ECWT is actually lower.
2. The primary effect is on kW/TR and it would be lower than the

corresponding values. Refer *Table 1* and *Chart 1*.

3. Current drawn by the compressor would also be lower for the same capacity produced. Refer *Table 1* and *Chart 2* and *3*.
4. Suction pressure would be optimum. Refer *Table 1* and *Chart 3* and *4*.
5. Discharge pressure would be lower than normal by up to 25 psig. Refer *Table 1* and *Chart 5*.
6. The effects of lower discharge and optimum suction pressures are:

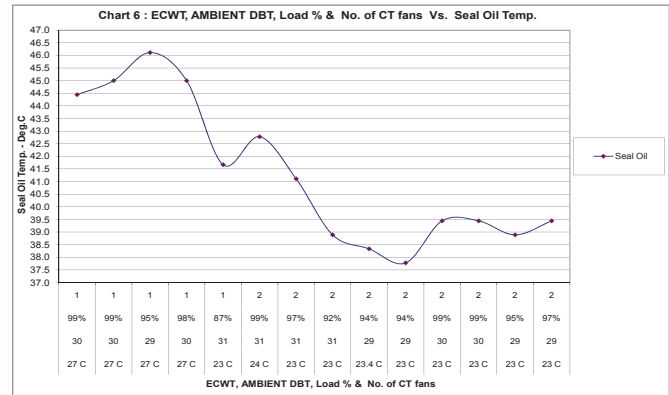
- a) Lower noise level from the compressor.
- b) Lower vibration.
- c) Oil pressure and differential oil pressure would be lower than normal, without decrease in lubrication to the parts inside the compressor.
- d) Ideal condition to minimize seal oil leakage.
- e) Seal oil temperature would be less. Refer Table 1 and Chart 6.
- f) Discharge superheat, sub cooling and suction superheat would be better.
- g) Compressor would be running at optimum conditions even for long hours of continuous operation for large temperature variations.
- h) Sustaining temperature difference at expected values across the evaporator and condenser. Refer Table 1 and Chart 7.
- i) The performance of evaporator and condenser would be enhanced to greater levels as the 'approach' on these equipment would be exceptionally good, which indicates better heat transfer.
- j) The better 'approach' on the evaporator and condenser would mean lower brushing/descaling frequency.
- k) Lower Leaving Condenser Water Temperature (LCWT) would help in reducing scale formation on condenser water piping as well.

Table 2: Effect of running additional CT fan

Amps saved	kW reduction in HT chiller	kW for addl. CT fan	Net kW savings
1	5.14	18.65	-13.51
2	10.29	18.65	-8.36
3	15.43	18.65	-3.22
4	20.58	18.65	1.93
5	25.72	18.65	7.07
6	30.87	18.65	12.22
7	36.01	18.65	17.36
8	41.15	18.65	22.50
9	46.30	18.65	27.65
10	51.44	18.65	32.79
11	56.59	18.65	37.94
12	61.73	18.65	43.08
13	66.87	18.65	48.22
14	72.02	18.65	53.37
15	77.16	18.65	58.51
16	82.31	18.65	63.66
17	87.45	18.65	68.80

7. With Chillers designed for higher ECWT, by maintaining ECWT at the lowest level, it is possible to beneficially operate the chillers in a progressive manner.

First situation: by maintaining lower current for the maximum capacity of the chillers when ambient is low and ECWT at its lowest.

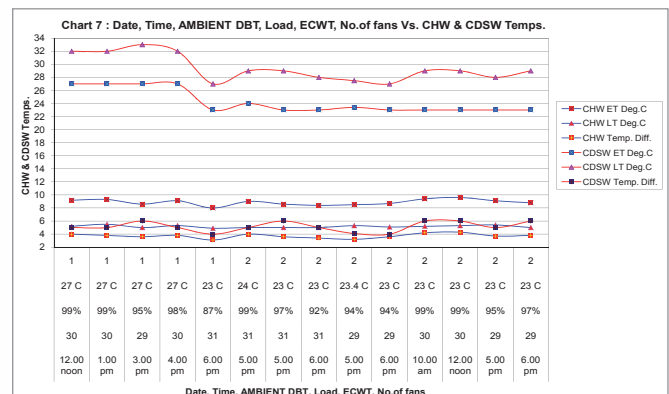
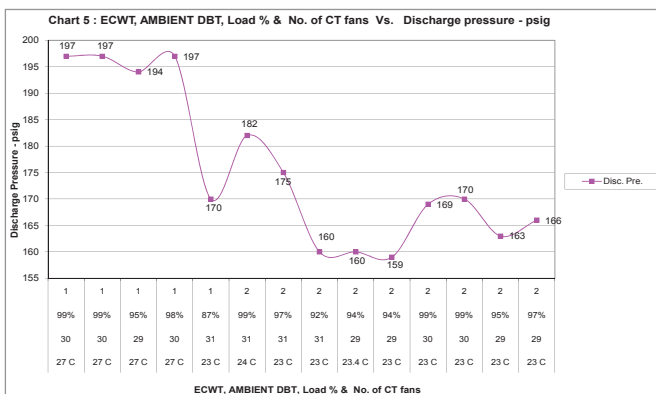


Second situation: with maximum capacity existing, based on the load addition, ambient temperature yet to rise and with slight increase in ECWT, the current would pick up and reach the full load limit.

Third situation: with maximum capacity existing, when the load increases further and ambient is rising, at this stage the chillers would still be producing further cooling, by maintaining the current at not more than the maximum level because ECWT would slowly rise to the acceptable level for which the chiller is designed. One can understand that till this third situation is reached, ECWT was at much lower level for the peak capacity of the chiller in the earlier two situations. Only after the third situation, when the chilled water outlet temperature is not maintainable, the operator/ automatic controls would call for additional chillers. Users are aware that constant flow rate through the evaporator and condenser should be maintained irrespective of the load side demand. Of course, it is very difficult to maintain the exact water flow rate required by the evaporator and the condenser. If the flow rate is higher through the evaporator and if we are still able to maintain the desired temperature difference, the benefit would be enhanced. Only due to this reason, +/- 10% of water flow rate is admissible through the evaporator and the condenser, and the kW/TR should not be more than 5% of the indicated value (as per agreed chiller evaluation standards).

Effect of Additional Cooling Towers

It is also seen that by running additional cooling tower/s, kW/TR could be reduced. This is once again due to the effect of lower



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Table 3: Comparison of chiller operation with combination of HT & LT chillers

Particulars	April 30, 2005		May 7, 2005		April 28, 2006		May 15, 2006		April 30, 2007		May 14, 2007	
	9.00 am	4.00 pm	9.00 am	4.00 pm	9.00 am	4.00 pm	9.00 am	4.00 pm	9.00 am	4.00 pm	9.00 am	4.00 pm
Ambient Temp. °C	33	35	32	34	33	35	32	34	33	35	32	34
HT open type comp. Chiller 1												
Chiller In temp. °C	7.9	7.9	8.1	7.5	10.7	8.1	8.8	8.2	10.3	9.4	10	9
Chiller Out temp. °C	5.5	5.6	5.5	5.1	6.8	5.6	5.9	5.2	6.2	5.3	6	5.6
Current - Amps	59	58	64	59	65	54	65	61	63	62	64	59
kW	303.51	298.36	329.23	303.51	334.37	277.79	334.37	313.80	324.08	318.94	329.23	303.51
HT open type comp. Chiller 2												
Chiller In temp. °C	-	-	-	-	10.2	8.3	8.4	7.9	-	-	-	-
Chiller Out temp. °C	-	-	-	-	6.7	5.2	6.1	5.5	-	-	-	-
Current - Amps	-	-	-	-	56.00	47.00	52.00	48	-	-	-	-
kW					288.07	241.78	267.50	246.92				
LT multi hermetic comp. Chiller												
Chiller In temp. °C	7.6	7.9	7.9	7.5	-	-	-	-	9.8	9	9.7	8.7
Chiller Out temp. °C	6.3	6.6	5.4	6.3	-	-	-	-	8.2	7.5	8	7.1
Current - Amps	317	304	344	302	-	-	-	-	240	250	250	239
kW	193.68	185.74	210.18	184.52					146.64	152.75	152.75	146.02
Chilled water temp. in supply header	5.90	6.10	5.45	5.70	6.75	5.40	6.00	5.35	7.20	6.40	7.00	6.35
Total power consumed kW	497.19	484.10	539.41	488.02	622.45	519.56	601.87	560.72	470.72	471.69	481.97	449.53
Remarks	One open type and one tandem chiller running. Here tandem chiller is not constrained.				Two open type chillers running.				One open type and one tandem chiller running. Here tandem chiller is constrained and only half the no. of compressors were intently "ON"			

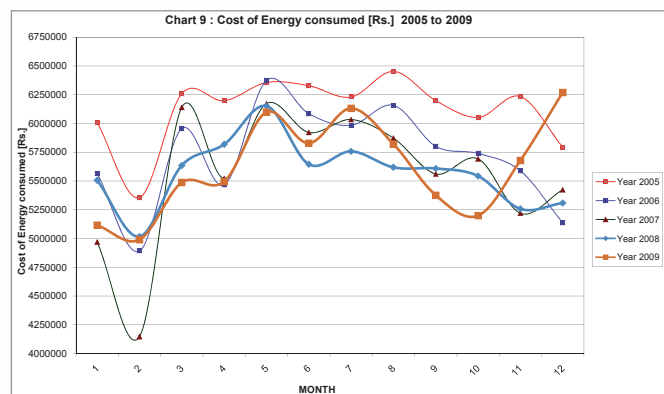
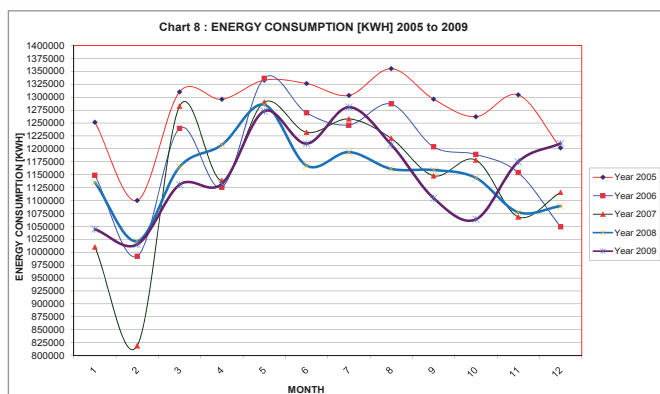
ECWT that is produced by the additional cooling tower/s. A proper balance should be struck while running the additional tower/s so that they are not run just to increase energy consumption. Table 2 clearly indicates that each ampere reduced at the compressor has an effect on power consumption. But running additional cooling tower/s offsets the same. At some point of time, the higher current saved by the compressor overcomes the effect of additional cooling tower/s.

Users need to analyze the chillers based on the above details and to decide when additional cooling tower/s should be run to lower the ECWT. It is decided at ISRO that whenever an open type compressor chiller is operated at loads 85% and upwards, an additional cooling tower should be switched on to check the current rise. Similarly, when two open type compressor chillers are operated and their individual loads are 85% and upwards, one common additional cooling tower helps in checking the current rise. When hermetic compressor chillers are working, by putting

off the cooling tower/s, we can save power consumption. But as already mentioned earlier, the system should be maintained at the lowest possible ECWT acceptable to the manufacturer, and the discharge pressure be maintained within the indicated/ acceptable pressure range. Cooling tower cycling can also be done in a progressive manner so that, depending on the number of hermetic compressors in operation, the cooling towers can be kept 'off' one by one, at the same time sticking to the acceptable ECWT. Extreme caution should be taken while carrying out cooling tower cycling. The plant should never be left unmanned when cooling towers are under cycling and when hermetic chillers are in operation. Cooling tower cycling should be done only under close attention of the operators.

Running Chillers in Combination

There are advantages in running chillers in combination when the hybrid plant has a combination open type and hermetic type chillers. Refer Table 3. The three classic examples below (Options

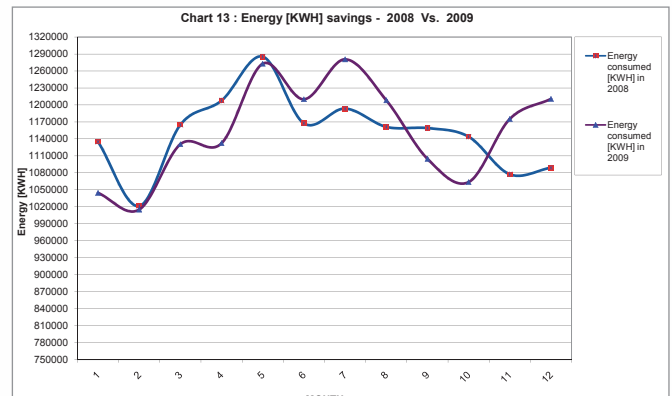
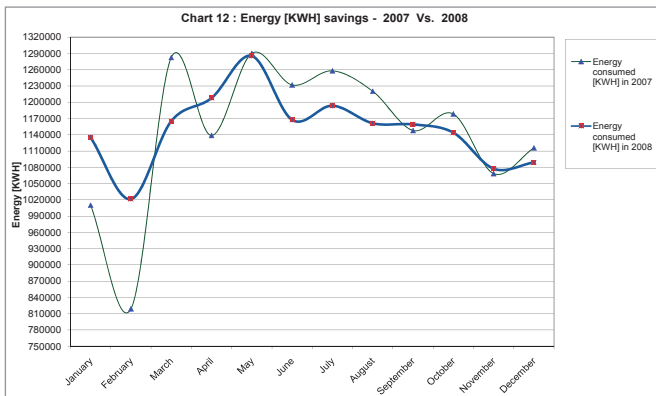
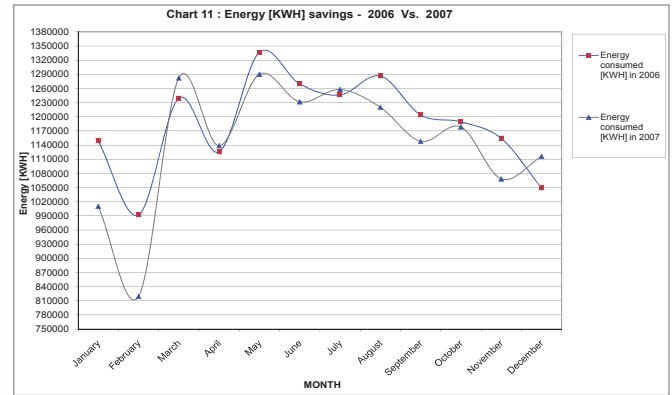
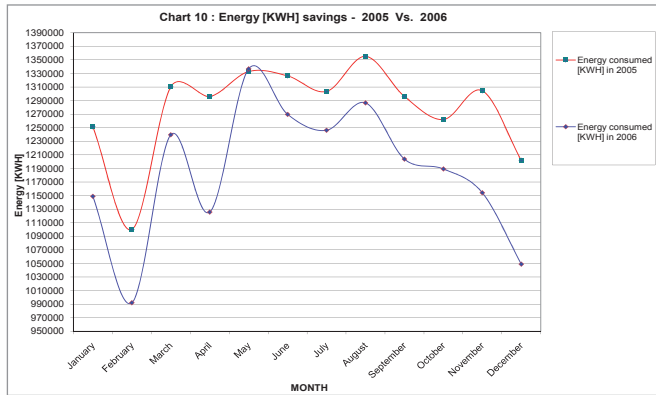


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Table 4: Power Consumption (kWH) and Cost Figures (Rs.)

	Year 2005		Year 2006		Saving in Rs. 2005-06	Year 2007		Saving in Rs. 2006-07	Year 2008		Saving in Rs. 2007-08	Saving in Rs. 2005-08	Year 2009		Saving in Rs. 2008-09	Saving in Rs. 2005-09
	kWH consumed	Amount Rs.	kWH consumed	Amount Rs.		kWH consumed	Amount Rs.		kWH consumed	Amount Rs.			kWH consumed	Amount Rs.		
January	1251480	6006364	1148880	5565184	441180	1010160	4968688	596496	1134960	5505328	-536640	501036	1044420	5,116,006	389,322	890,358
February	1100100	5355430	992100	4891030	464400	819000	4146700	744330	1021440	5017192	-870492	338238	1015080	4,989,844	27,348	365,586
March	1310160	6258688	1239540	5955022	303666	1282400	6139320	-184298	1165020	5634586	504734	624102	1130580	5,486,494	148,092	772,194
April	1295880	6197284	1125660	5465338	731946	1138680	5521324	-55986	1207740	5818282	-296958	379002	1132380	5,494,234	324,048	703,050
May	1332780	6355954	1336740	6372982	-17028	1290180	6172774	200208	1285320	6151876	20898	204078	1272840	6,098,212	53,664	257,742
June	1326300	6328090	1269600	6084280	243810	1231800	5921740	162540	1167540	5645422	276318	682668	1210020	5,828,086	-182,664	500,004
July	1303440	6229792	1246200	5983660	246132	1257900	6033970	-50310	1193580	5757394	276576	472398	1280580	6,131,494	-374,100	98,298
August	1355100	6451930	1286580	6157294	294636	1220220	5871946	285348	1161240	5618332	253614	833598	1208280	5,820,604	-202,272	631,326
September	1296060	6198058	1203780	5801254	396804	1147860	5560798	240456	1159020	5608786	-47988	589272	1104660	5,375,038	233,748	823,020
October	1262040	6051772	1189260	5738818	312954	1178340	5691862	46956	1143840	5543512	148350	508260	1063680	5,198,824	344,688	852,948
November	1304400	6233920	1154160	5587888	646032	1068300	5218690	369198	1077360	5257648	-38958	976272	1175100	5,677,930	-420,282	555,990
December	1201950	5793385	1048920	5135356	658029	1115880	5423284	-287928	1089180	5308474	114810	484911	1210560	6,269,104	-960,630	-475,719
	15339690	73,460,667	14241420	68,738,106	4,722,561	13760720	66,671,096	2,067,010	13806240	66,866,832	-195,736	6593835	13848180	67,485,870	-619,038	5,974,797
Total savings compared to 2005			4,722,561			6,789,571			6,593,835				5,974,797			



1 to 3) would help to decide the best way to operate to suit one's need.

Option 1: Energy Conservation - One Open Type and One Tandem Chiller Running

Here, tandem chiller is constrained and only half the numbers of compressors are 'ON'. Power saving is achieved by maintaining the upper limit of the chilled water outlet temperature based on the acceptable inside design conditions (room conditions) from the users.

Note: Cooling more than required and reheating wastes energy and should never be allowed.

Option 2 : Process Requirement -Two Open Type Chillers Running

This is the ideal situation when it is required to meet the critical process requirement of chilled water temperature combined with general loads. Here, process needs are to be met.

Option 3: Feel Easy: One Open Type and One Tandem Chiller Running

Here, the tandem chiller is not constrained. This gives us an idea of what happens when the tandem chillers are not constrained in comparison to Option 1, where only half the number of compressors in the tandem chiller are run.

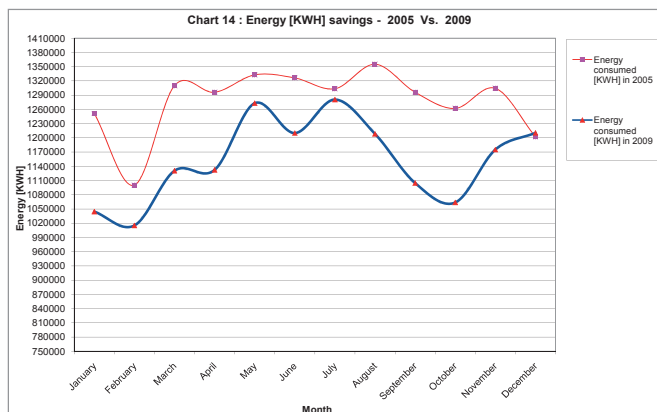
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Table 5: Effect of de-scaling

	CDSW IN TEMP		CDSW OUT TEMP		DST °F	APPROACH °F	SP	DP	SLIDE	AMPS	CDSW FR USGPM	PD in psig	No. of hrs run	Remarks	
	°C	°F	°C	°F											
HT CHILLER 1															
Before	26	78.8	29	84.2	90.2	6	67	169	99	62	1950	4		To clean the condenser physically or chemically once the approach reaches 5.0°F (this is concluded by comparing the approach after the present cleaning)	
After	26	78.8	29	84.2	86.7	2.5	67	160	99	60	1950	4	2000		
Before	25	77	28	82.4	87.9	5.5	70	163	99	66	1950	4			
After	25	77	29	84.2	85.5	1.3	64	157	98	59	1950	4	2000		
HT CHILLER 2															
Before	27	80.6	29	84.2	95.4	11.2	72	183	92	61	1950	4			
After	27	80.06	30	85.46	87.9	2.44	70	163	92	54	1950	4	5940		
HT CHILLER 3															
Before	27	80.6	29	84.2	94.3	10.1	73	180	74	50	1950	4	5040		
After	26	78.8	29	84.2	86.7	2.5	69	160	75	48	1950	4			

Table 6 : When to do your next de-scaling/ brushing of tubes?

	CDSW IN TEMP		CDSW OUT TEMP		DST °F	APPROACH °F	SP	DP	SLIDE/ load %	AMPS	CDSW FR USGPM	PD in psig	No. of hrs run before descaling	Remarks	
	°C	°F	°C	°F											
CHILLER 1															
Before														To clean the condenser physically or chemically once the approach reaches ___°F (this is concluded by comparing the approach after the present cleaning)	
After 1 day															
After 1 month															
After 3 months															
After 6 months															
After 1 year															
CHILLER 2															
Before															
After 1 day															
After 1 month															
After 3 months															
After 6 months															
After 1 year															
CHILLER 3															
Before															
After 1 day															
After 1 month															
After 3 months															
After 6 months															
After 1 year															



Effect of Energy Conservation on the Power Bill

Implementation of the above energy saving exercise is substantiated by the data at the above location. Tables 4 and Charts 8 to 14 for the years 2005 to 2009 show the power consumption and its cost. The effective saving, with 2005 as the base year, is Rs. 47.23 lakh in 2006, Rs. 67.90 lakh in 2007, Rs. 65.94 lakh in 2008, and Rs. 59.75 lakh in 2009. Considering no additional load in 2009, the cumulative saving from 2006 to 2009 is Rs. 240.82 lakh, on an investment of Rs. 255 lakh. This pay-back is encouraging. Data is being acquired even now to ensure that the energy conservation is sustained.

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Chiller Management Logic for Combination of Chillers

1. The system foreseen is ---Nos. x ---- TR (----- compressor typeworking on ---- supply).
2. The software shall decide on individual or combinations of chiller packages that will require the least kW per TR for the air-conditioning system. The data from chiller manufacturer shall be used for this purpose. The data of chillers, pumps, cooling towers, AHUs, packaged units and fan coil units shall be used to specify on screen the repair/troubleshooting/maintenance work to be undertaken by the operator.
3. While switching 'ON' the AC plant, the chiller package that has run the least number of hours has to come 'ON' first. In case of multiple compressor chiller packages, the compressor that has run the least number of hours has to be come 'ON' first. The other chiller packages/compressors have to come 'ON' in ascending order of running hours in either case.
4. Load sharing between the chillers must be possible. If it is multiple compressor type, if one compressor is having more than 80% load, the chiller package shall call for the next least number of hours run compressor and both these compressors shall together share the load, which is more than 80% for a single compressor. If the total load is more than what two compressors can handle (i.e., 80% load factor on each compressor is in fulfilled condition), the third compressor of the chiller package shall come 'ON' and all the three compressors shall, together, share the load. While sharing the load, each compressor shall be loaded to 80% initially, then depending on the total demand, equal loading factor on individual compressors shall be decided and brought down in steps.

Note: For achieving the above, while DDC system could be foreseen to do the run time equalization for the entire chiller system, in case of multiple compressor chiller package the controls built into the chiller shall have the provision for run time equalization amongst the compressors within such a system when the DDC gives the command for the multiple compressor chiller

package to come ON. Alternatively, the multiple chiller packages should have access (to accept switching commands for individual compressor and also give feed back to DDC regarding number of compressors working) for switching ON the individual compressors from the DDC.

5. When the power supply is through local Electricity Board power source, any chiller package or any combination of single compressor type and multiple compressor type chiller packages shall be able to operate, subject to a maximum of ----- chiller packages. When the power supply is through DG set, the chiller package with multiple compressors shall start first. Then, depending on the load, additionally, any one of the single compressor type shall be put 'ON', subject to a maximum of ----- chiller packages. Due to any reason, if the multiple compressor chiller package could not be operated, there should be an override to put 'ON' any ----- single compressor type chiller packages.
6. During the lean hours, i.e. between 7pm and 7am (12 hours) and during winter season, the chiller package consuming the least kW per TR shall be given preference according to the load profile loaded in the software. Due to any reason, if a particular type of chiller package could not be operated, there should be override to put 'ON' any other working chiller package.
7. Individual or combinations of chiller packages for run time equalizing, load sharing, sequencing and using the available power supply through local Electricity Board or DG source, throughout the day, month and year shall be automatically decided by the software. Overrides/ user defined mode of operation shall always be available to overcome any circumstance and to enable the discretion of the plant in-charge.
8. The central chiller system software as well as software residing in DDC shall provide a facility for nominating any one of the chiller packages as standby by suitable selection on the chiller screen or through the Portable Operator Terminal (POT), over and above the load sharing, sequencing and run time equalization facilities called for in the above paragraphs.

Effect of De-Scaling

The paradigm on de-scaling/brushing of tubes of evaporators and condensers reads that it has to be carried out as soon as the approach/ leaving temperature difference increases more than 2°F as compared to clean condition. The effect of de-scaling can be understood from *Table 5*. The blank *Table 6* could be used to login data to know the exact timing for the next de-scaling/ brushing of tubes.

Conclusion

Chiller performance has to be continuously analyzed with possible combinations and various parameters that can be adjusted so as to achieve the least power consumption. It is imperative that chiller buyers make it a point to know the minimum ECWT at which the chiller could operate. The chiller that is intended to operate at the lowest ECWT would be the most energy efficient. Also, it is strongly recommended to buy a chiller that:

Improving Chiller Efficiency

- (a) Has the lowest cooler and condenser approach (LTD) values,
- (b) Would not surge/could operate even at low loads of the order of 25% or lower, while at the same time maintaining a power factor of 0.95 or better. Usage of energy efficient motors IE-3 or premium efficiency and guaranteed (subject to tolerance) for 50°C would be handy to achieve these objectives.

Chiller manufacturers claim various capacity control techniques, viz. VFD for compressor motor, discharge diffuser for centrifugal chillers and slide valve positioning for screw chillers. Oil free lubrication for centrifugal chillers using ceramic ball bearings for radial and axial loads coupled with gearless operation and magnetic levitation centrifugal compressors are the latest with VFD operation. But the focus is always on the least kW/TR that is expected of the chiller. Today, DDC systems are available in many locations. It would be better if a chiller management software/logic is included in the DDC system based on the actual condition in each location to achieve better results.

There should be combined effort by the client, chiller manufacturer and DDC vendor to see that the least kW/TR is maintained on air-conditioning systems. Extreme caution is required during such analysis, especially when the important parameters on hand are varied. New equipment are expensive and any downtime is unaffordable. ❁