Selection of 3X400 Ton Centrifugal Water Chillers for Central AIC Plant --- A Case Study

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SELECTION OF 3X400 TON CENTRIFUGAL WATER CHILLERS FOR CENTRAL A/C PLANT — A CASE STUDY

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ABSTRACT

The selection of a centrifugal system for chilling water and its optimum location have been carried out in the present case study based on (a) energy conservation, (b) economy and (c) operation and maintenance. The comparison is done between the R-11 open and R-12 hermetic centrifugal water chillers (CWCs). Thermodynamic analysis for 400 ton renders the capacity of the former to be 8 ton higher than that of the latter. The former is also found to be better than the latter for airconditioning and inferior to the latter for heat pump use. Moreover, for the year round airconditioning the hermetic unit stands a better position.

The evaluation of various quantities based on the location of the central CWCs shows an additional expenditure of Rs. 1.4 million for the plant of Rs. 13.6 million due to (a) 79 kW of loss of refrigeration by heat transfer, (b) 16 kW of refrigeration loss due to more pumping energy, (c) 16 kW of increased pumping power and increased cost of larger size pumps and (d) losses of power and more maintenance cost. Further, the use of ozone friendly and proven refrigerants like R-717 and R-718 is stressed.

INTRODUCTION

For airconditioning of production centres, industrial and academic buildings, lecture theatres, research laboratories, health centres, airports etc., it is common practice to prefer centralized water chiller (WC). Its advantages are: (a) *low initial investment, (b) better COP, (c) reduced maintenance cost, (e) noise free airconditioning, (f) better temperature and humidity control, etc.* The selection of such system, or replacement or augmentation of existing units needs detailed comparative study [1]. In the present case over two decade old 720 ton central reciprocating water chillers (RWCs) were found to be too inadequate to meet the new developments. Hence it was decided to add 1200 ton (3x400 ton) CWCs out of available R-11 open type and R-12 hermetic type CWCs and R-22 screw water chiller (SWC). Though the SWC possesses most of the desirable properties, including very low ozone depletion potential (ODP) and its permissible use up to 2010 A.D., the high cost and unavailability of 400 ton unit eliminated it from the competing group. The power of plant is 0.99 kW/ton where power for the circulation of chilled water alone accounts for 132 kW for a flow rate of 228 kg/s for three units.

The case study encompasses about the site for installation of CWCs. The following factors may be considered in addition to commonly used parameters:

i. Adequate space for the plant room at the load centre.
ii. Permitted vibration and noise level.
iii. Tolerance of moisture in the surrounding area
iv. Aesthetic requirements of adjacent structures.
v. Location of electric substation/source of power supply.

How best these factors can be overcome depends, upon whether the CWCs are planned for an old or a new establishment. Because in the former the existing buildings bring about various limitations. Thus, it is not possible to select site as per minimum cost consideration or convenient location. In the latter there can be proper planning for space for various buildings and CWCs. However, the site for central CWC should be as close to the load centre as possible. Any major shift of site from the load centre would lead to (a) *use of larger capacity plant, (b) increased initial cost, (c) more power for refrigeration systems, (d) increased maintenance cost, (e) more efforts for the controlling system etc.*

The present case falls under the old category. Hence there is no free hand for allocation of site as per normal practice. As such the same is bound to violate some norms for the optimum choice of the site. Nevertheless, a close look on the system layout (Fig. 2) reveals that plant is far away from the load centre.

PLANT ROOM SPACE

The floor area , the room space and type of the system are recommended based on long experience. But there is no proper guideline for the same, causing problems in accommodating various units. Table 1 gives floor areas for central CWCs of some owners. It shows large variation in the floor area, needing a careful study. In the present case the recommended floor area of 185 m^2 was inadequate for installation of three 400 ton CWCs. Hence a floor area of 324 m^2 (i.e., 75% more) was proposed. But due to some practical constraints 103 m^2 of floor area was added for eight pumps for condenser and evaporator units. Hence Table 1 would be useful to the consultant/plant engineers for deciding space for CWCs.

Table 1
Floor areas for various capacities of CWCs.

Centrifugal water chiller	Owner of Units	Capacity numberxtons	Plant Room mxm = m^2
Hermetic Compressors	British High Commission, New Delhi	3x180 ton each = 540 tons	14.4x18.3 = 445
Open type compressor Hermetic Compr.	National Inst. of Immunization New Delhi	2x180 ton each = 380 tons 1x180 tons Total 540 tons	18.3x12.2 = 223
Open Type compressor	American Centre	3x180 ton each = 540 tons	1.2x10.7 = 162
Hermetic Compressor	Post Graduate Institute, Lucknow	3x450 ton each 1x450 ton* Total 1800	24.4x20.4 =498
Open Type/ Hermetic Comprs.	IIT Kanpur	3x400 ton each = 1200 tons	15.2x12.2 = 185

* To be installed # Original recommended value of floor area

POWER INPUT TO OPEN AND HERMETIC UNITS

The power input to hermetic and open units were estimated based on their ratings and COPs [2]. The same are presented in Table 2. The open type R-11 CWC for a given cooling capacity is seen to be better for airconditioning than that of the R-12 hermetic unit due to the following:

i. Actual COP of the open type chiller is 1.88% higher
ii. The evaporator capacity of the hermetic unit is larger by 2.273%
iii. The condenser of the hermetic unit is higher by 4.495%
iv. Power consumption of the hermetic unit is 4.236% higher.

For the heat pump operation, the R-12 hermetic CWC is superior to that of the R-11 open type due to the following reasons:

i. Performance index is 2.484% higher
ii. Heating effect is 4.495% higher
iii. The installation cost is lower as compared to the open type.

Table 2

Comparison between 400 ton open and hermetic CWCs for airconditioning and heat pump applications.

System	Power, kW	Evaporator capacity, kW/ton	Condenser capacity, kW	COP	Remark
Open type	305.25	1400/400	1674.73	5.096	For aircondi-
Hermetic	318.18	1431.82/409.09	1750	5.00	tioning
% Change #	4.236	2.273	4.495	-1.884	applications
Open type	305.25	1400/400	1674.725	5.4864*	For heat pump
Hermetic	318.18	1431.827 409.09	1750	5.500*	
% change#	4.236	2.273	2.495	2.484	operation

Table 3

Comparison between open and hermetic centrifugals for 400 ton (1400 kW) of heating for the same data as used in table 2.

System	Q_h[kW(ton)]	Q_c[kW(ton)]	P(kW)	PI	Remark
Open type	1400(400)	1170.33(334.38)	255.17	5.486	Heat pump
Hermetic type	1400(400)	1145.44(327.27)	254.54	5.50	operation
% change#	0.00	- 2.216	- 0.246	0.246	

* Performance Index. # over open type.

The comparisons between the R-11 open and R-12 hermetic systems for the same warming capacity for the heat pump operation give the following results:

i. The hermetic unit has performance index 0.246 higher
ii. The evaporator is 2.216% smaller iii. Power input is less by 0.246%.

The *motor sizes* for the hermetic and open types help determine kVA of the substation. The KVA requirements for the R-11 open type and R-12 hermetic units with all CWCs starting at a time were estimated as 1600 and 2600 KVA, respectively. But all motors and compressors are not started at a time. They should be switched on one by one. Under this case the respective values become 1500 kVA and 1800 kVA.

MATHEMATICAL MODELING FOR SITE SELECTION

Figure 1 shows a typical layout of various sections with cooling loads. The pipe diameters can be selected using allowed velocities or by some economic model [4]. Then the optimum location of the central CWC can be found on the basis of minimum total cost or cooling load centre. Hence,

$$TR = \sum_i TR_i \qquad (1)$$

If c_i is the cost of cooling load (including material and maintenance cost per unit distance from the load centre and per unit of refrigeration capacity, the total cost is found to be:

$$C = \sum_i TR_i \left[(x_i - X)^2 + (y_i - Y)^2\right]^{1/2} c_i \qquad (2)$$

Then the optimum location of the central CWC may be obtained from:

$$dC = 0 = \frac{\partial C}{\partial X} dX + \frac{\partial C}{\partial Y} dY = 0$$

i.e.,

$$\frac{\partial C}{\partial X} = 0 = \sum_i TR_i \frac{(x_i - X)\, c_i}{\sqrt{(x_i - X)^2 + (y_i - Y)^2}} = 0 \qquad (3a)$$

$$\frac{\partial C}{\partial y} = 0 = \sum_i TR_i \frac{(y_i - Y)\, c_i}{\sqrt{(x_i - X)^2 + (y_i - Y)^2}} = 0 \qquad (3b)$$

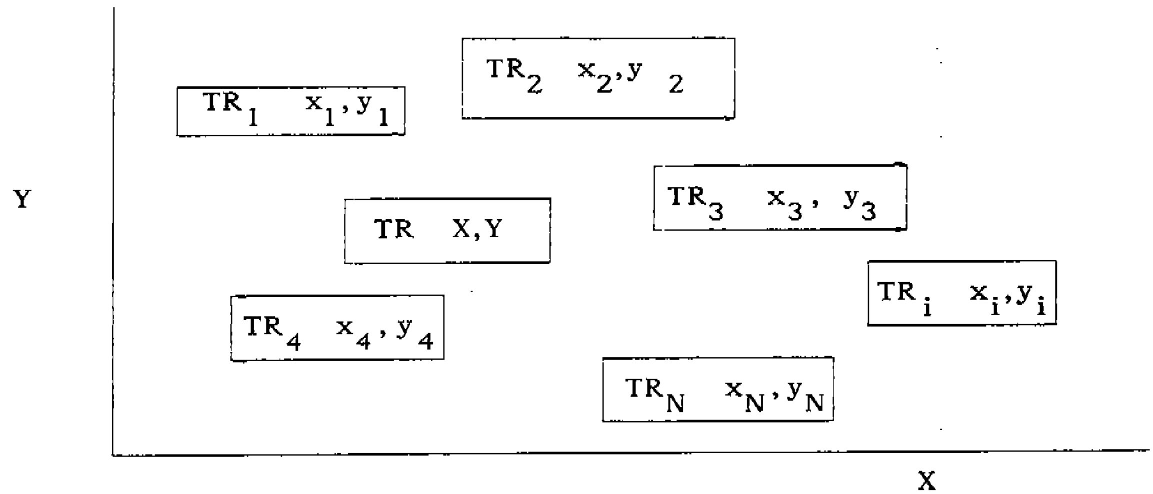

Fig. 1: Schematic N numbers of cooling loads for different users.

Power for Nn pumps, each pumping V volume of water against a total pressure drop of Δp and with the pump efficiency of η_p is calculated from:

$$P = Nn\ V\Delta p/\eta_p \qquad (4)$$

Here Δp is found from Eq.(5) using Δp_i as pressure drop in the ith line as:

$$\Delta p = \sum_i \Delta p_i \qquad (5)$$

$$C_{total} = \sum_i [L_i\, c_i + C_{eff}\ OH\ [V_i'\ \Delta P_i + TR_i'/COP]] \qquad (6)$$

where
- L Length of pipe measured as per layout for the section
- c_i Cost of piping including insulation and maintenance.
- C_{eff} Effective cost of electricity due to escalation [3] $= n. \sum_{i'} c_{ei'}/(1 + I)^{n-1}$ OH = operating hours /year
- n Life of the system & $c_{ei'}$ as cost of electric unit in the i'th year
- TR_i' Tonnage due to pumping energy and heat transfer to chilled water.

Equations (3a&b) are solved simultaneously to get the optimum location (X_o, Y_o) using numerical method. The values of c_is are obtained from the available commercial data from various suppliers, users, consultants, etc [4]. The above

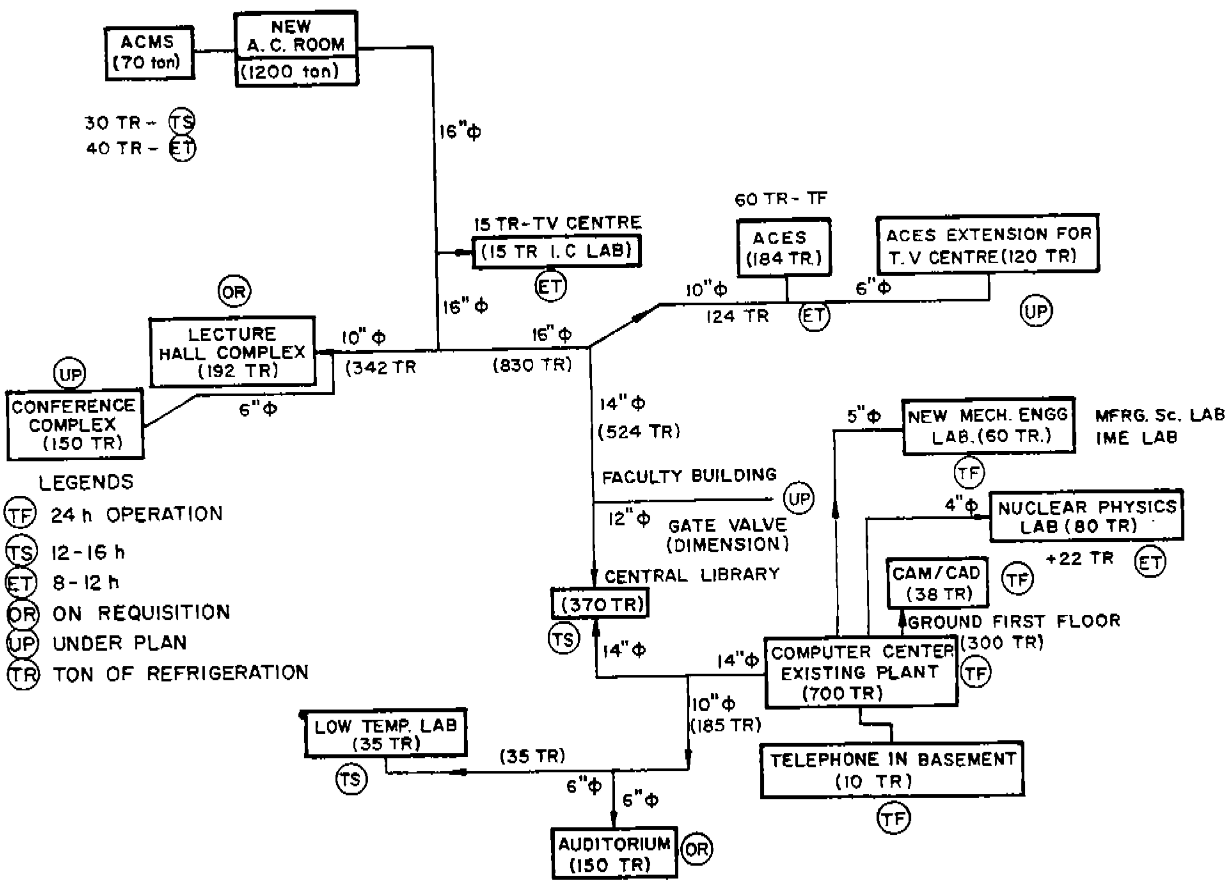

Fig.2. The cooling loads and the present CWCs plant layout.

general approach can be adopted for a new establishment to get the cheapest system with a minimum damage to existing buildings. However, in case of old category a few compromised sites for the central CWCs are selected after assessing various constraints. Then cost analyses are carried out for all of sites for the selection of the one with a minimum cost. Figure 2 is the layout of the present case study. The calculated values using Eq. (6) for the same are given in Table 4. The additional amount of Rs. 1.4 million incur due to the Rs. 13.6 million plant being located away from the load centre.

Table 4

Additional cost estimation for the present layout

Additional cost for						additional amount in Lakhs
Pumping and Refrig.		47.94 kW				Rs. 5.15
Refrigeration system		22.57 tons				Rs. 3.78
Additional cost for pimping						
Pipe Dia. (mm)	length (m)	Rate (Rs/m)	Planned	Modified	Difference	
450	100	2045	2,04,500	-		
400	100	1960	1,96,000	-	0.085	
400	200	1960	3,92,000			
150	200	300		6,0000	3.32	
400	275	1960	5,39,000			
300	275	1390		3,82,250	1.57	Rs. 4.975

USE OF OZONE FRIENDLY REFRIGERATION SYSTEMS FOR CWC

The ozone depletion is posing serious problems to the refrigeration industry and thereby to the modern developments. The concerted efforts had led to development of ozone friendly refrigerants R-123 and R-134a as substitutes of R-11 and R-12, respectively. But the same has also been found to have effects on mammals as reported by Dr. Allen Knit of Griffith University, Australia. It is the need of the hour to adopt proven refrigerants for ODP free operation rather than temporarily tackling the problem. As such attention has been focused on the use of the following refrigerants or refrigeration systems.

i. Non-azeotropic mixtures of R-22 and R-152a for refrigerator [5]
ii. R-22 for screw compressors for central WC
iii. Single-stage and Multi-stage ammonia refrigeration systems and multi-stage centrifugal compression for chilled water for airconditioning [6-8].
iv. Lithium-Bromide-water vapour absorption system being developed by several leading refrigeration industry for airconditioning.

Out of the above, the non-azeotropic mixture of R-22 and R-152a may be considered for automobile airconditioning as well . Similarly, there is a need of rethinking about use of R-22 beyond the Montreal Protocol of 2010 AD as its ODP is only 0.05 as compared to ODP of 1 for R-12 or R-11. This much depletion of ozone may be compensated for by the natural process of ozone formation.

CONCLUSIONS

1. Space for the plant room should be selected carefully.
2. The central CWC should be installed as close to the load centre as possible in order to avoid large initial investment and running expenditure.
3. The substation capacity is dependent upon the type of CWCs.
4. The open and hermetic unit have distinct merit for the airconditioning and heat pump operations. Hence their selection needs proper analysis.
5. The ozone hole is posing serious problem due to the use of CFCs, requiring rethinking for switching over to ammonia and water or even to R-22.

REFERENCES

1. Carrier,Willis H., et al, *Modern Air Conditioning, Heating, and Ventilating*, 3rd Edn. Pitman Publishing Corporation, 1959, pp. 369-73.
2. Jim, V.L., "A Trane Airconditioning Seminar- Excellence Continues", Sept 11, 1989, New Delhi.
3. Prasad, R., Optimum Design of Multistage Vapour-Compression Refrigeration System, M. Tech. Dissertation, Mech. Engg. Dept. IIT Kanpur, December, 1983.
4. Stoecker, W.F., and J.W. Jones, *Refrigeration and Airconditioning*, 2nd Edn. TMH, 1982, pp. 134-36.
5. Wu, Y, G. Xie and X.Z., Li, Development of a High-Efficiency Domestic Refrigeration Using CFC Substitutes, Int. J. Refrigeration, Vol. 17, No.3, 1994, pp. 205-208.
6. Prasad, Manohar, Multi-stage Water and ammonia Refrigeration Systems, in the Light of Ozone Hole Problem, International Refrigeration Conference; Energy , Efficiency and New Refrigerants, July 14-17, 1992, pp. 295-301.
7. G. Lorenzen, G., Ammonia an Excellent Alternative, Int. J. Refrig., Vol. 11, No. 4, 1988, pp. 248-52.
8. Stoecker, W.F., Expanded Applications for Ammonia - Coping with Release to Atmosphere, Int. J.. Refrigeration, Vol. 13, No.2, 1990, pp. 86-94.