Design, Development And Testing the performance of Evaporative Condenser in air conditioning System

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Contents

MOTIVATION

- Air conditioner is not a luxurious device now a days

- Power consumption

OBJECTIVE

- To reduce the power consumption of air conditioner by replacing the conventional condenser with evaporative condenser.

- Getting the benefit of subcooling of liquid

INTRODUCTION

Vapour Compression Refrigeration (VCR)System

Main components of VCR cycle

1. Compressor
2. Condenser
3. Expansion Valve
4. Evaporator

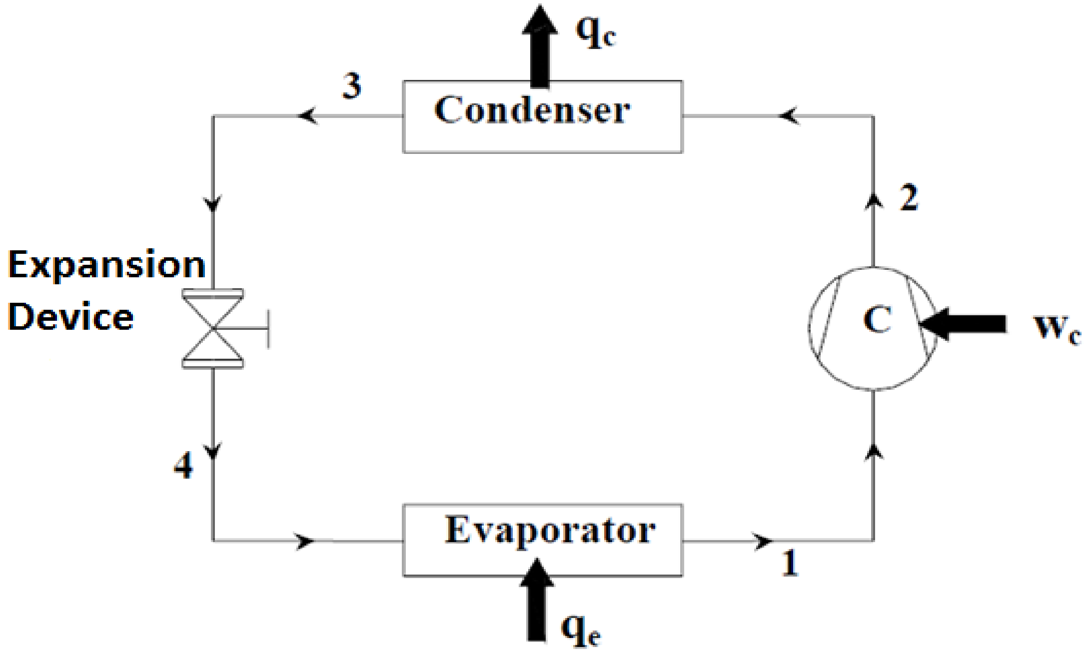


Fig. Schematic diagram of VCR cycle's components

T-s and p-h diagram of VCR cycle

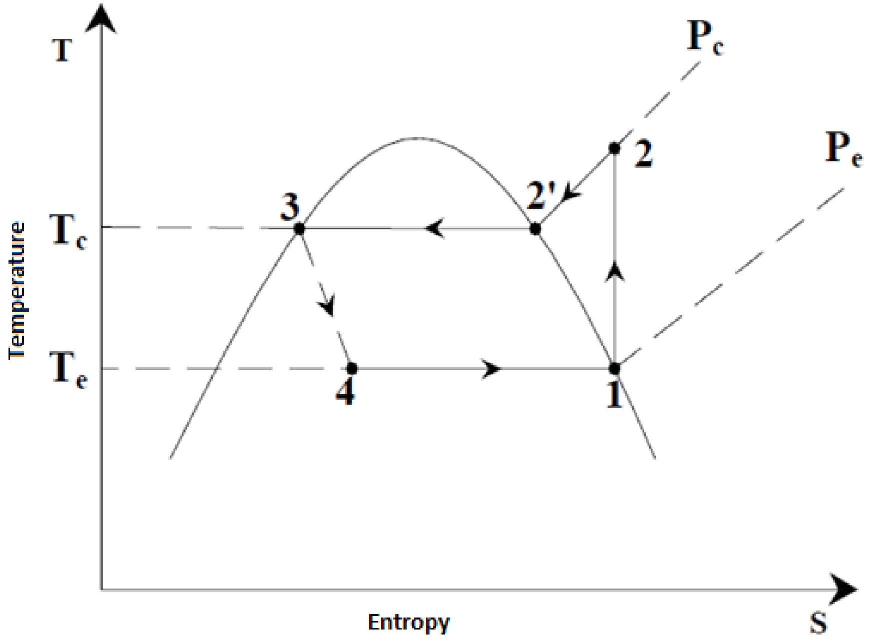


Fig. T-s Diagram of VCR

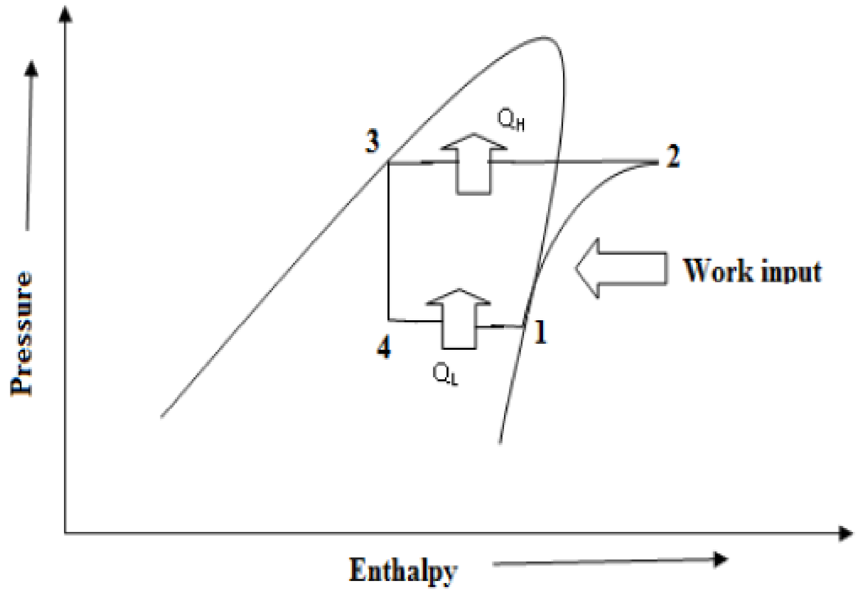


Fig. p-h Diagram of VCR

Cooling Tower

- The primary task of a cooling tower is to reject heat into the atmosphere.

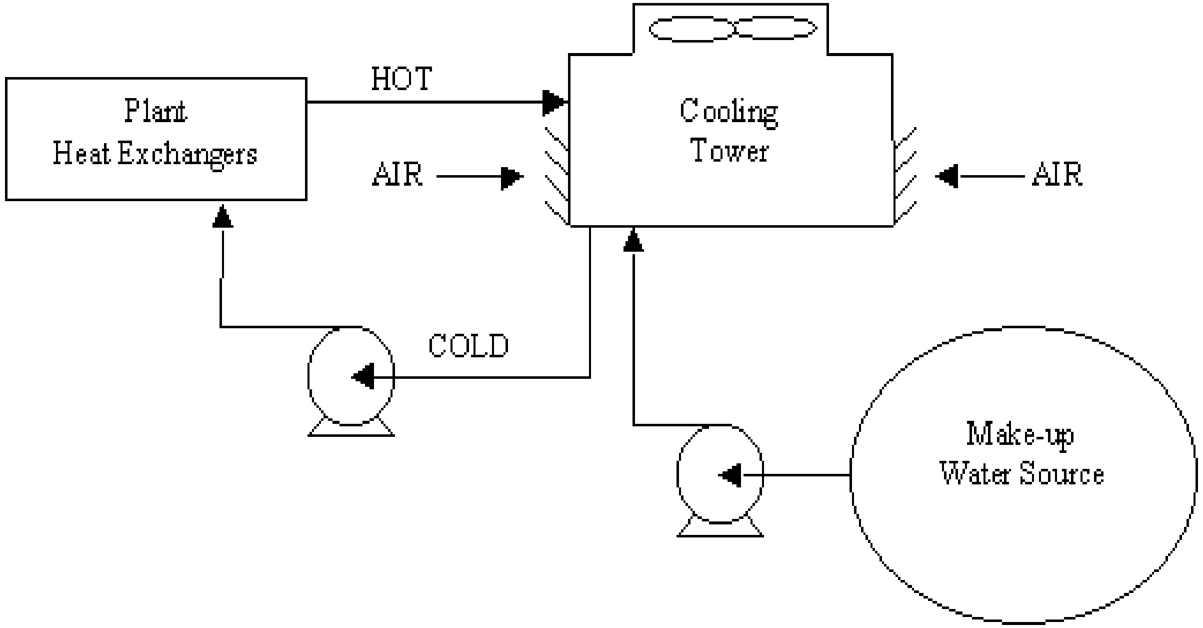


Fig. Schematic diagram of Cooling Tower

Effect of techniques

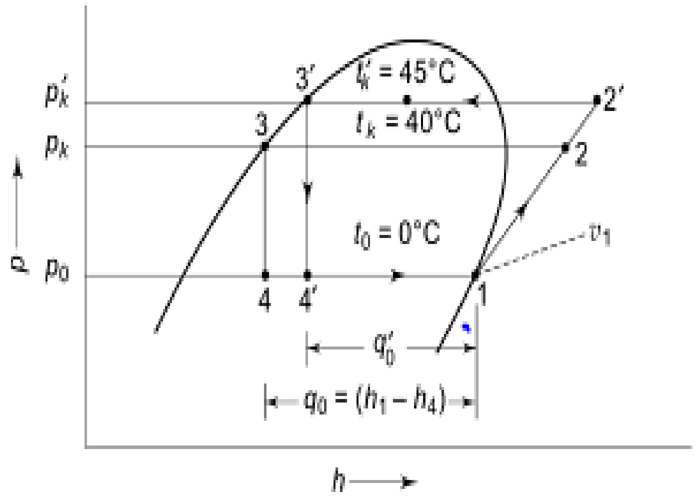


Fig. p-h diagram of VCR cycle with evaporative condenser

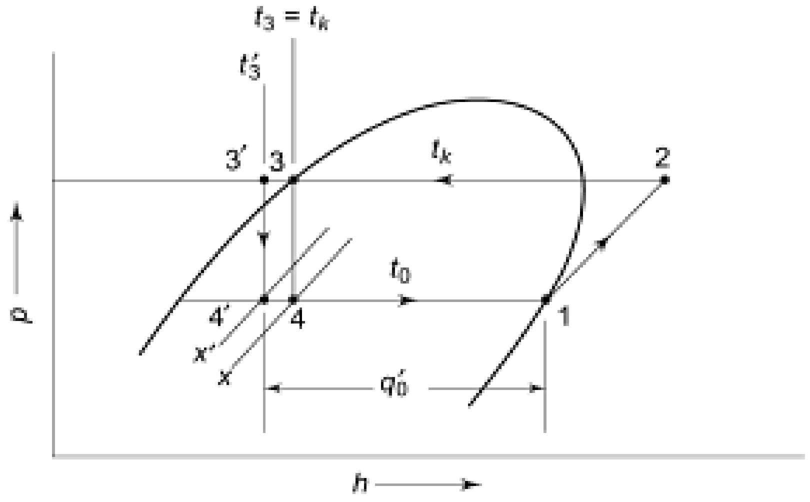


Fig. VCR cycle with sub cooling

Research paper review

Sr. no.	Title	Review
1.	Performance improvement of air-cooled refrigeration system by using evaporatively cooled air condenser [1] E. Hajidavalloo, H. Eghtedari; 29 January 2010	This paper show that by using evaporatively cooled condenser instead of air cooled condenser the power consumption can be reduced up to 20% and the COP can be increased up to 50%.
2.	Experimental and theoretical investigation of an innovative evaporative condenser for residential refrigerator[2] M.M. Nasr, M. Salah Hassan; 28 March 2009	This paper shows that the evaporative condenser can operate at a condensing temperature of 20˚C lower than that of the air-cooled condenser for heat flux of 150 W/m2, and at air velocity 3 m/s. The effect of the different parameters on the condenser temperature was studied too.
3.	Proposal of an eco-friendly high-performance air-conditioning system. Part 1. Possibility of improving existing air-conditioning system by an evapo-transpiration condenser [3] Huynh Thi Minh Thu, Haruki Sato; 15 April 2013	In this paper it is shown that by replacing the air cooled condenser in conventional air conditioning system with the evaporation and transpiration condenser the power consumption is reduced up to 30%, and the COP is at least 4 times higher.

Research paper review cont…

Sr. no.	Title	Review
4.	Experimental investigation of air conditioning system using evaporative cooling condenser [4] Tianwei Wanga, Chenguang Shenga, A.G. Agwu Nnannaa; 5 July 2014	This paper shows that by using evaporatively cooled condenser in air conditioning system the power consumption can be reduce up to 14.3% and the CP is increased up to 6.1 to 18%. This paper shows the relation between water consumption and compressor energy saving regarding to their cost.
5.	Application of evaporative cooling on the condenser of window-air-conditioner[5] Ebrahim Hajidavalloo; 10 January 2007	This paper shows that by incorporating evaporative cooling in window air conditioner, the thermodynamic properties of the new system are improved and the power consumption decreases by about 16% and the coefficient of performance increases by about 55%.
6.	Optimal Subcooling in Vapor Compression Systems via Extremum Seeking Control: Theory and Experiments[6] Justin P. Koeln, Andrew G. Alleyne; 16 March 2014	Simulation and experimental results show there exists an optimal subcooling which maximizes system efficiency that changes with operating conditions. Experimental results shows that using the alternative architecture and extremum seeking control efficiency is increased by 9%.
7.	Design and rating of an integrated mechanical-subcooling vapor-compression refrigeration system[7] Jameel-ur-Rehman Khan, Syed M. Zubair; 2000	In this paper, a new subcooler cycle is developed to replace the simple subcooling system. The improvements are related to the refrigerant saturation temperature of the subcooler.

Research paper review cont…

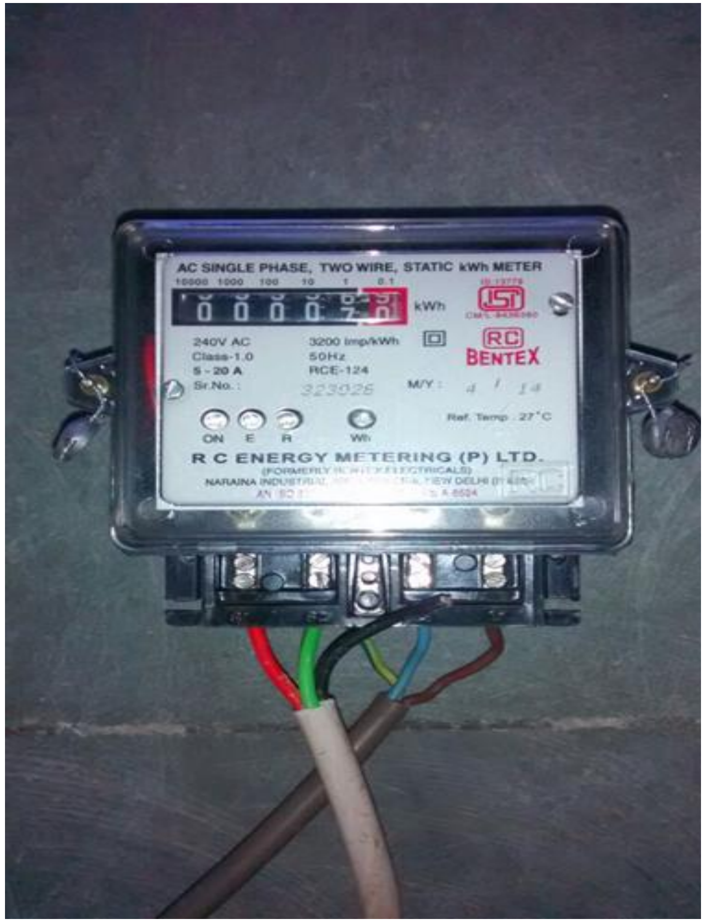
Sr. no.	Title	Review
8.	**An experimental evaluation of a residential-sized evaporatively cooled condenser**[8] Yunho Hwang, Reinhard Redermacher, William Kopko; January 2000	This paper shows a comparison between innovative evaporatively cooled condensers with conventional air cooled condenser for a split heat pump system. After all the test, it is found that evaporatively cooled condenser has higher capacity by 1.8 to 8.1%, higher COP by 11.1 to 21.6% and higher SEER by 14.5%.
9.	**Modeling the performance characteristics of water-cooled Air-conditioners** [9] W.L. Lee, Hua Chen, F.W.H. Yik; June 2008	In this paper, an empirical model was developed to predict operation performance and energy consumption. A prototype WACS was set up and tested in an environmental chamber. The COP was found greater to 3 at 90% rated capacity.
10.	**Mechanical sub-cooling vapor compression systems: current status and future directions**[10] Bilal Ahmed Qureshi, Syed M. Zubair; July 2013	In this paper numerical and experimental works were considered for the purpose of highlighting the progress of mechanical subcooling in vapor compression system. Some important results were discussed and some suggestions were made to provide direction into future research.

System


SAMSUNG
R CONDITIONER
AWT18F1MD
TY(COOLING)
18000BTU/h
GE/FREQUENCY
200-220V~,50Hz
10.5A
2050W
IGERANT
(R22)
1480g
15 AMP. TIME DELAY FUSE
CIRCUIT BREAKER.
DESIGN
PRESSURE
HIGH
21.0kg/cm²
LOW
10.5kg/cm²
ERIAL NO : P2ENB02972
OMP. THERMALLY PROTECTED.
AMSUNG ELECTRONICS CO.,LTD.
ADE IN KOREA

Instruments used

Sr. no.	Instrument	Purpose
1.	Air conditioner	For Modification and Testing
2	Energy meter	For measuring power consumption of A.C.
3.	Digital temperature indicator	To measure temperature of refrigerant at various stages.



Energy meter(Mechanical type)

Digital temperature indicator(pt100)

Initial calculation for the system

1. **Length of condenser**

length of condenser pipe= 1.204×32= 38.52 meter

2. Power consumption

Ideal power consumption = 2050 Watt (from A.C. specification)

Calculated power consumption = 2329.4 Watt

Design calculation[B7]

T °C	ρ kg/m^3	C_p kJ/kg-K	$\mu \times 10^6$ N-s/m^2	k W/m-K	Pr	$\beta \times 10^4$ 1/K	$\nu \times 10^6$ m^2/s	$\sigma \times 10^4$ N/m
0	999.9	4.212	1787.8	0.551	13.67	−0.63	1.789	756
10	999.7	4.191	1305.3	0.575	9.52	+0.70	1.306	742
20	998.2	4.183	1004.2	0.599	7.02	1.82	1.006	727
30	995.7	4.174	801.2	0.618	5.42	3.21	0.805	712
40	992.2	4.174	653.1	0.634	4.31	3.87	0.659	696
50	988.1	4.174	549.2	0.648	3.54	4.49	0.556	679
60	983.2	4.179	469.8	0.659	2.98	5.11	0.478	662
70	977.8	4.187	406.0	0.668	2.55	5.70	0.415	644

Properties of water

Design calculation cont…

For water at temperature 30 ^oC

1. $P_r = \frac{\rho \upsilon C_p}{k} = 5.41 \times 10^{-3}$.....[B1]
2. $R_e = \frac{\rho v L}{\mu} = 2292$.....[B2]
3. $N_u = \frac{hD}{k} = 3.66 + \frac{0.0668(D/L)\mathrm{Re}.\mathrm{Pr}}{1 + 0.04[(D/L)R_e.P_r]^{2/3}} = 4.34$.....[B3]
4. $N_u = 0.664(R_e)^{0.5}(P_r)^{0.333} = 5.36$......[B4]
5. $N_u = \frac{hL}{k}$....[B5]
   i. For $N_u = 4.34, h = 436 W/m^2K$

   i. for $N_u = 5.36, h = 558.7 W/m^2K$

Design calculation cont…

T (K)	μ_f (10^{-4} Pa·s)	μ_g (10^{-4} Pa·s)	k_f (W/m·K)	k_g (W/m·K)	$\bar{v}_{sf}$ (m/s)	$\bar{v}_{fg}$ (m/s)	Pr_f	Pr_g	σ (N/m)
150			0.161						
160			0.156						
170	7.70		0.151			142.6	5.39		
180	6.47		0.146			146.1	4.69		
190	5.54		0.141			149.4	4.16		
200	4.81		0.136		1007	152.6	3.77		0.024
210	4.24		0.131		957	155.2	3.47		0.022
220	3.78		0.126		909	157.6	3.24		0.021
230	3.40	0.100	0.121	0.0067	862	159.7	3.07	0.89	0.019
240	3.09	0.104	0.117	0.0073	814	161.3	2.92	0.89	0.017
250	2.82	0.109	0.112	0.0080	766	162.5	2.83	0.89	0.0155
260	2.60	0.114	0.107	0.0086	716	163.1	2.78	0.89	0.0138
270	2.41	0.118	0.102	0.0092	668	163.4	2.76	0.90	0.0121
280	2.25	0.123	0.097	0.0098	622	162.1	2.77	0.93	0.0104
290	2.11	0.129	0.092	0.0105	578	161.1	2.80	0.97	0.0087
300	1.98	0.135	0.087	0.0111	536	160.1	2.86	1.04	0.0071
310	1.86	0.141	0.082	0.0117	496	157.2	2.96	1.13	0.0055
320	1.76	0.148	0.077	0.0123	458	153.4	3.14	1.25	0.0040
330	1.67	0.157	0.072	0.0130	408	148.5	3.39	1.42	0.0026
340	1.51	0.171	0.067	0.0140	355	142.7	3.55	1.60	0.0014
350	1.30		0.060		290	135.9	3.72		0.0008
360	1.06								
369.3									

[a] Notation –4 signifies $\times 10^{-4}$.
[b] Notation –3 signifies $\times 10^{-3}$.
[c] Critical point.
From Kakaç, S. and Yener, Y. (1995) *Convective Heat Transfer*, 2nd ed., CRC Press, Boca Raton, FL. With permission.

Design calculation cont…

- From the above table, we find the values at 318 K by interpolation,
- $\frac{T_{318}-T_{320}}{T_{310}-T_{320}} = \frac{V_{g_{318}}-0.01265}{0.01643-0.01265}$
- $V_{g_{318}} = 0.013406 \quad \Rightarrow \rho_{g_{318}} = 74.59\ Kg/m^3 \ \left(since\ \rho_g = \frac{1}{V_g}\right)$
- $similarly,\ V_{f_{318}} = 9.02 \times 10^{-4} \quad \Rightarrow \rho_{f_{318}} = 1108.3\ Kg/m^3 \left(since\ \rho_f = \frac{1}{V_f}\right)$
- $\mu_{f_{318}} = 1.78 \times 10^{-4} pa \cdot s$
- $\mu_{g_{318}} = 1.1466 \times 10^{-4} pa \cdot s$
- $Pr_f = 3.104$
- $Pr_g = 1.226$

Design calculation cont…

- $K_{g(318)} = 0.01218, \quad K_{f(318)} = 0.078$
- $X_{tt} = \left(\frac{1-x}{x}\right)^{0.9} \left(\frac{\rho_v}{\rho_l}\right)^{0.5} \left(\frac{\mu_l}{\mu_v}\right)^{0.1}$
- $where, \left(\frac{1-x}{x}\right)^{0.9} = 1 = 1 \times \left(\frac{74.59}{1108}\right)^{0.5} \left(\frac{1.78}{0.1466}\right)^{0.1} = 0.333$
- $f_c = 3.28 \times \left(\frac{1}{X_{tt}}\right)^{0.78} = 7.7333$

For condenser coil,

- $d_o = 0.375\ inch, d_i = 0.305\ inch, t_h = 0.035\ inch, A_b = 0.073 in^2,$
- $d_i = 7.747 \times 10^{-3} m$
- $A_i = \frac{\pi}{4} {d_i}^2 = 4.7112 \times 10^{-5} m^2$
- $(R_e)_l = \frac{\rho\mu D}{K} = \frac{1108.3 \times 7.74 \times 10^{-3} \times 0.7877}{1.78 \times 10^{-4}} = 3800$

Design calculation cont…

- Finding value of h for refrigerant (convection coefficient)

1. Chang hyo son, ho-saevglee[11]

- $N_u = \frac{h_r \times D_i}{K_l} = 0.034 \times {Re_l}^{0.8} \times {Pr_l}^{0.3} \times f_c(X_{tt})$

$$\therefore \; h_r = 2705.55\, W/m^2K$$

2. M. P. K. Doboon[12]

- $N_u = \frac{h_r \times D_i}{K_l} = 0.06 \times (Re_l)^{0.8} \times {Pr_l}^{0.3} \times \left(\frac{1}{X_{tt}}\right)^{0.505}$

$$\therefore \; h_r = 1507\, W/m^2K$$

3. Dobson and Chato[13]

- $N_u = \frac{h_r \times D_i}{K_l} = 0.023 \times {Re_l}^{0.8} \times {Pr_l}^{0.4} \times \left[1 + \frac{2.22}{{X_{tt}}^{0.89}}\right]$

$$h_r = \frac{K_l}{D_i} \times 0.023 \times {Re_l}^{0.8} \times {Pr_l}^{0.4} \times \left[1 + \frac{2.22}{{X_{tt}}^{0.89}}\right]$$

$$\therefore h_r = 1851.72\, W/m^2K$$

Design calculation cont…

- Overall heat transfer coefficient:
- $\frac{1}{U_i A_i} = \frac{1}{h_i A_i} + \frac{ln\left(\frac{r_o}{r_i}\right)}{2\pi K l} + \frac{1}{h_o A_o}$
-
- $where, h_i = 2705\ (refrigerant)$
- $h_o = 558\ (water)$
- $D_o = 0.00952$
- $D_i = 0.00774$
- $Q_c = 7609.4$
- $\Delta T_{lm} = 17.86$
- $K = 385$
- $U_i A_i = 438.92$

Design calculation cont…

- $\frac{1}{h_i D_i} = 0.047763$
- $\frac{1}{h_o D_o} = 0.188247$
- $\frac{ln\left(\frac{D_o}{D_i}\right)}{2K} = 0.0002688$
- $sum\ of\ all\ R = 0.236279$
- $Usefull\ length\ of\ condenser = 33.02\ m.$

Design calculation cont…

- **Calculation of pump**

  Mass flow rate of water,

$$Q_c = \dot{m} C_p \Delta T_w$$

$$7609.4 = \dot{m} \times 4.18 \times 10^3 \times 5$$
$$\dot{m} = 0.364\ Kg/s$$

Fabrication

Testing

TIME	METER READING(KWh)	T_1 (°C)	T_2 (°C)
11:00	46.85	15.2	29
11:30	48.21	14.5	28.7
12:00	49.48	15.3	28.6
12:30	50.1	14.8	27.3
01:00	51.2	14.3	28
01:30	53.43	15.2	28.8
02:00	54.8	15.1	29.3
02:30	56.45	15.7	29.9
03:00	57.7	14.2	29.4
03:30	58.7	14.6	29.4
04:00	60	14.5	29.4
04:30	61.38	14.8	29.8
05:00	62.83	15.3	29.8

testing of system without evaporative condenser

TIME	METER READING(KWh)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)
11:00	34.2	17.4	27.2	34.2	34.3
11:30	35.1	11.7	26.1	33.3	38.2
12:00	35.7	11.4	27	33.1	34.7
12:30	36.6	13.6	25.9	38.8	38.3
01:00	37.4	15	26.3	37.1	36.5
01:30	38.1	15.0	26.4	36	34.9
02:00	38.9	14.1	26	36.6	35.1
02:30	39.55	15.7	27.1	36.5	34.2
03:00	40.2	14.1	26.8	35.8	33.9
03:30	40.8	12.1	26.8	39.5	36.5
04:00	41.85	12.9	27.3	32.5	34.5
04:30	42.35	13	26.5	38.1	37.5
05:00	43.2	13	26.5	38.3	35.8

testing of system with evaporative condenser

Results of testing

- **Without using evaporative condenser**
- Mass flow rate of cooling air

$$\dot{m} = \rho A V$$

$$\dot{m} = 1.2688 \times 0.0384 \times 0.62 = 0.302\ Kg/s$$

- Cooling capacity, Q_e

$$Q_e = \dot{m} \times C_p \times \Delta T$$

$$Q_e = 0.302 \times 1005 \times (29.03 - 14.88) = 4294.66\ Watt$$

- Power consumption, W_p

$$W_p = \frac{16 \times 3600000}{6 \times 3600} = 2663.33\ Watt$$

- Coefficient of performance, COP

$$COP = \frac{Q_e}{W_p} = \frac{4294.66}{2663.33} = 1.61$$

- **With using evaporative condenser**
- Mass flow rate of cooling air

$$\dot{m} = \rho A V$$

$$\dot{m} = 1.2688 \times 0.0384 \times 0.62 = 0.302\ Kg/s$$

- Cooling capacity, Q_e

$$Q_e = \dot{m} \times C_p \times \Delta T$$

$$Q_e = 0.302 \times 1005 \times (26.60 - 13.77) = 3894.03\ Watt$$

- Power consumption, W_p

$$W_p = \frac{9 \times 3600000}{6 \times 3600} = 1500\ Watt$$

- Coefficient of performance, COP

$$COP = \frac{Q_e}{W_p} = \frac{3894.03}{1500} = 2.65$$

- % decrease in power consumption

$$= \frac{2663.33 - 1500}{2663.33} \times 100 = 43.68\%$$

- % increase in COP

$$= \frac{2.65 - 1.61}{1.61} \times 100 = 64.6\%$$

- Effect on cost

Reduction in power consumption = 16-9 = 7 unit (for 6 hours in one day)

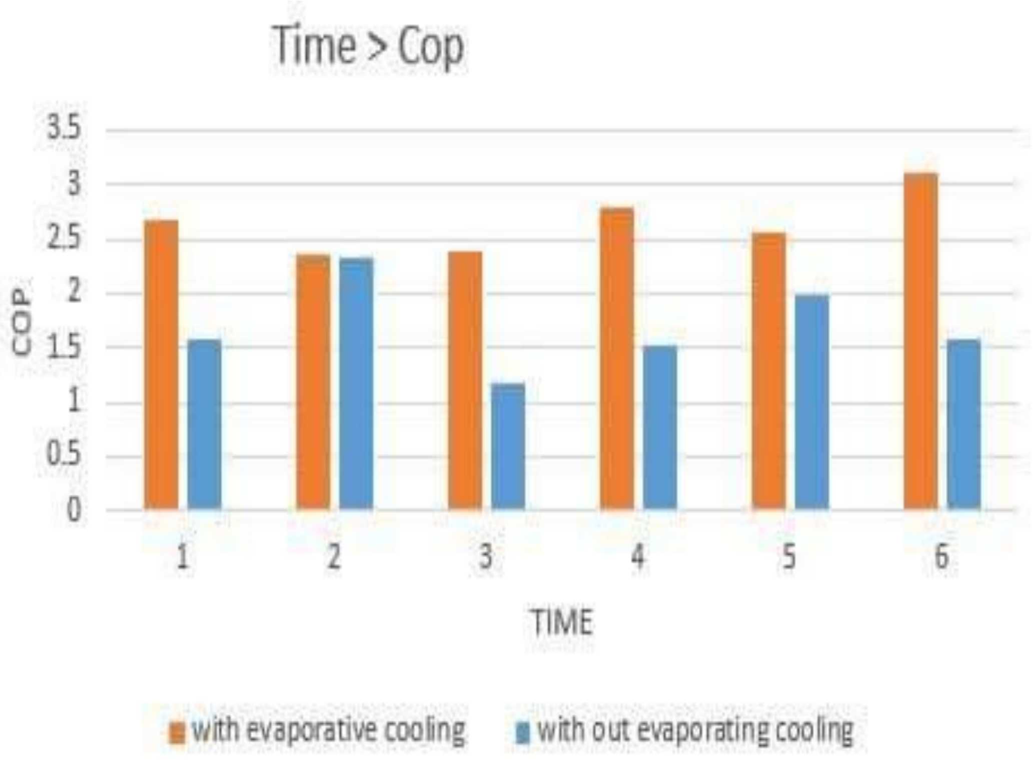
Saving in cost = unit saved × charge of 1 unit

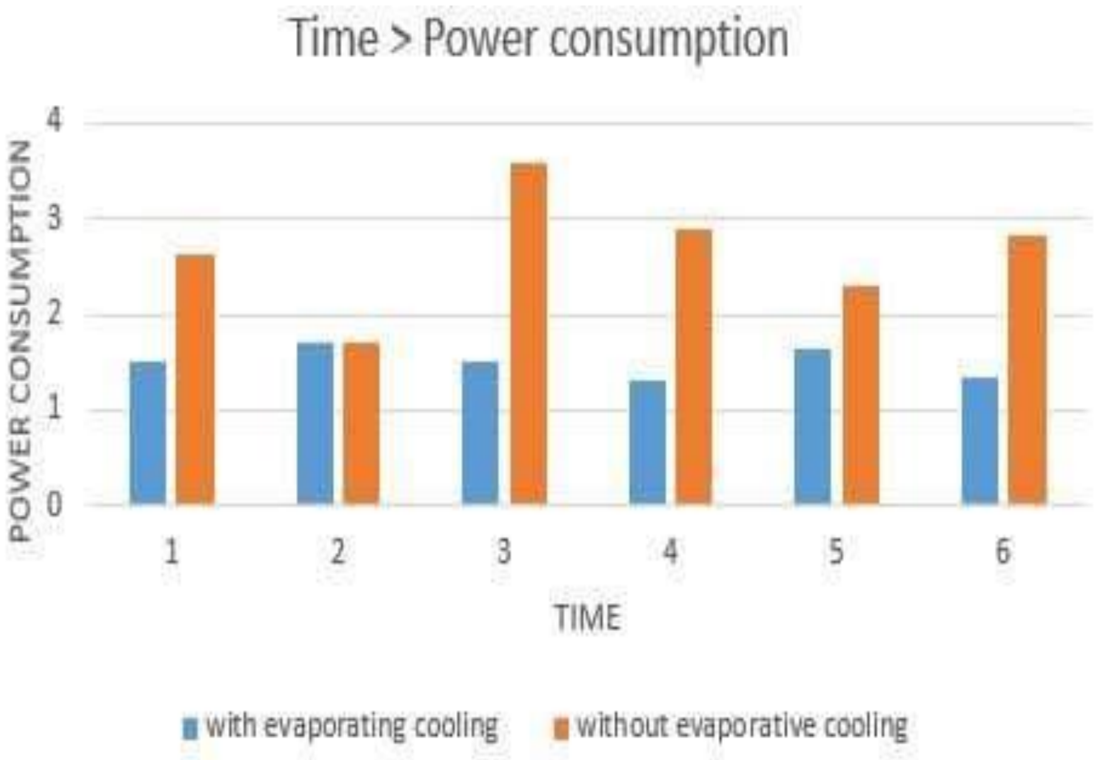
= 7 × 4.5 (approx.)

= Rs. 31.5

- Saving for 4 months = 31.5 × 122 = Rs 3843

Variation in per consumption and COP with time





Conclusion

- By adopting evaporative condenser the power consumption reduced by 1163 watt

- C.O.P. of system is increased by 64.6%.

- This modified and efficient method can save 3843 RS. Per 4 months.

Reference

Papers

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Books

[B1] Er. R. K. Rajput, Heat and Mass Transfer, S Chand, Edition 2011, Pg. 366

[B2] Er. R. K. Rajput, Heat and Mass Transfer, S Chand, Edition 2011, Pg. 366

[B3] Er. R. K. Rajput, Heat and Mass Transfer, S Chand, Edition 2011, Pg. 465

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[B6] Er. R. K. Rajput, Heat and Mass Transfer, S Chand, Edition 2011, Pg. 45

[B7] Sukhatme, Solar Energy, Tata McGraw-Hill Education, Appendix-4, Pg. 415

WEBSITES

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[W2] [india.in/energy_managers_auditors/documents/guide_books/3Ch7.pdf

THANK YOU