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Simulation of an Air Conditioning System using Applications of Evaporative Cooling for Optimum Energy Use

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ABSTRACT

Performances of vapor compression air conditioners are suboptimal during torrid climatic conditions due to reduced heat exchange in its air-cooled condenser resulting in a drop in Coefficient of Performance because of the high-pressure ratio of the compressor. In this study performance of an alternative model is presented to overcome this subpar performance. A simulation of the window air conditioning system has been carried out on Cool Pack simulation software using R-22 as a refrigerant. For simulation 5.275 KW refrigerant capacity of window air conditioning system was considered. The experimental results of the window air conditioning system using air-cooled condenser and evaporative condenser for the same working conditions validated by Cool Pack simulation software are presented. The results show a significant improvement in Coefficient of Performance and reduced power consumption by using evaporative condenser compared to air-cooled condenser. An increase in refrigerant effect and decease in compressor work, mass flow rate is also observed.

Keywords: evaporative condenser, simulation, energy saving, air -cooled condenser, coefficient of performance.

1. INTRODUCTION

Vapor compression refrigeration system is generally employed for all comfort air-conditioning applications in particular tropical countries like India where it is mostly used to reduce the DBT and RH of the atmospheric air. Satisfactory performance of such air conditioners during the torrid climatic conditions has always been challenging as with the rise in DBT there is a significant drop-in rate of heat exchange between the compressed refrigerant and atmospheric air in the condenser. This suboptimal rejection of heat by the refrigerant affects all the design parameters of the air conditioner and its satisfactory performance is compromised up to a certain extent.

Various alternatives and improvements have been suggested and are being used to overcome this periodic difficulty. A simple improvement in the heat exchange process in the condenser by inserting a wet padded layer of any porous material could be a useful option. Induced air from the condenser fan would affect the evaporation of moisture present in the layer and thus cool the air before coming in to contact with the condenser coil. This will increase the temperature differential between the cooling air and the liquid high-pressure refrigerant and a better cooling can be achieved. This application is particularly very effective under hot and dry atmospheric conditions as such conditions are conducive to evaporative cooling. This hypothesis is tested and validated in the following sections.

2. BACKGROUND STUDY

Many researches has been reported related works .Some of them are given below:-

Dr. Boda Hadya [1] simulated outcomes of vapour compression refrigeration system with superheating and sub-cooling for comparing the system analysis for refrigerants of R22, R32, and R410A. For analysis simulated results of R410A and R32 refrigerants compared with experimental results of R22. By using refrigerant R32 and R410A reduce power consumption in air conditioning compared to R22 refrigerant. Results show that by using sub cooling and superheating improves the coefficient of performance and reduce power consumption. Sharma and Katarey [2] have been done a cost-benefit investigation of the window air conditioning system using an application of an evaporative cooled condenser. The performance of the air conditioning system investigated without evaporative condenser and with evaporative condenser. The experimental results presented that evaporative condenser, the coefficient of performance (COP) improved up to 41.94% and compressor power consumption reduced up to 46.76 % compared to without evaporative cooling condenser. The cost-benefit analysis of an evaporative condenser has been performed. The results presented that according to the present electricity rate in India, the payback period of the evaporative condenser system is less than three years. Venkataiah and Rao [3] performed a simulation analysis of the refrigerants i.e. R-22, R-134a, R404A, R407C, R410A, R290, R507A, and R600a on CoolPack software. It is found that R410A can be selected as a similar refrigerant to replace R22 in air conditioning systems as its displacement volume is much lower and also discharge temperatures are lower as compared to R22. BodaHadya [4] presented the simulation study of different refrigerants namely R22, R32, and R410A in vapour compression refrigeration system. R32 is an environmental free refrigerant that can be used in air conditioning applications, because of zero Ozone Depletion Potential and having 650 Global Warming Potential which is low compare to R22. For high ambient conditions if the condenser temperature at 55°C and evaporator temperature of 10˚C, Coefficient of Performance for Refrigerant 32 is 3.37, R410A is 3 and for R22 is 2.55. The air conditioning system with the same operating conditions, the power required for R22 is 0.8976 kW, R32 is 0.575 kW and R410A is 0.61 kW per one "TR" capacity.

Hajidavalloo [5], [6] performed a test on the window air conditioning system using an application of an evaporative cooling condenser. He retrofitted two cooling pads, where the air is sucked by the blower to cool the condenser and then water is sprayed on the cooling pads so that entering air temperature decreases due to evaporative cooling. It is found that the coefficient of performance improved up to 55% and power consumption reduced up to 16%. Dhamneya et al. [7] compared the performance evaluation of the ice plant test apparatus with an evaporatively cooled condenser and TiO2-R134a nano refrigerant. The experimental results show that an evaporatively cooled condenser is better than TiO2-R134a nano refrigerant during the torrid season. It is found that COP increases 51% by using evaporative condenser. Chaktranonda et al. [8] investigated analysis in a split air conditioner with an evaporative condenser for energy saving. The investigation shows that COP improved from 6 % to 48% and compressor power consumption decreased from 4% to 15%. Alotaibiet et al. [9] investigated of air conditioning system using air-cooled condenser with water spraying. Experimental results showed that compressor power consumption reduced up to 20 % and COP improved about 24%. Hao et al. [10] investigated air-cooled chiller to save energy by using the application of an evaporative cooling condenser. They retrofitted evaporative cooler near to the condenser of an air-cooled chiller. It is observed that by using evaporative cooling, energy consumption reduced from 2.4 % to 14 %. Khandelwal et al. [11] used evaporative cooling as well as regenerative evaporative cooling to a water-cooled chiller. By using evaporative cooling with water-cooled chiller reduces power consumption 12.05 % and while using regenerative evaporative cooling reduces 15.69 annually power consumption. Kulkarni et al. [12] compared conventional cooling and evaporatively cooled condenser for split type air conditioner. It found by using an evaporatively cooled condenser that COP improved up to 22 % and energy consumption reduced up to 16.7 %. It is also found by using an evaporative cooled condenser, condenser temperature drops from 40°C to 28°C and refrigerant effect increased up to 16.7 %.

3. METHODOLOGY

Window air conditioning test rig is used for experimental results, which consists of 1.5 T sealed compressor unit, fins and tube type air cooled condenser, double ended shaft motor and evaporator. A digital temperature indicator displays temperature at suction to compressor, discharge to compressor, outlet from condenser and inlet to evaporator, a voltmeter to measure voltage and ammeter to measure current. Rota meter is connected between the compressor and expansion devices, which is used to measure refrigerant mass flow rate. A drier is placed between rota meter and evaporator to remove moisture particle from the refrigerant, which is flowing refrigeration cycle. Window air conditioning test rig is placed at S.A.T.I. (Engineering College), Vidisha, Madhya Pradesh. Evaporative condenser has been retrofitted near to the condenser. Evaporative condenser consists of a water tank, water circulation pump, water pipe with nozzles and honeycomb pad [13].In evaporative cooler is used to spray water

Water circulation pump of very small power is used to spray water on the honeycomb pad in evaporative cooler. Due to spray of water on the cooling pad near to the condenser, temperature of condenser reduces rapidly so that the pressure ratio reduces.

Fig. 1 Window air conditioning trainer

Fig. 2.Evaporative cooler retrofitted to condenser

After steady state condition, firstly readings are recorded air-cooled condenser and then evaporative condenser with 30 minutes interval. In air –cooled condenser first point readings are calculated by following calculations using p-h chart. At point one suction pressure (P_1) is 4.4 bar and discharge pressure (P_2) is 24 bar.

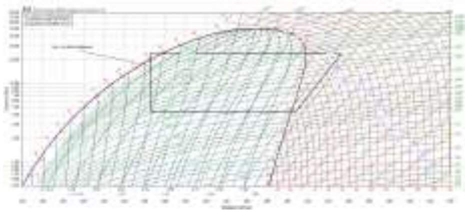

Fig. 3.The P-h diagram for Air- cooled condenser

Assuming superheating =6°C,
sub cooling=8°C
Enthalpy at inlet of compression, h_1=405 kj/kg
Enthalpy at outlet from compression, h_2=452 kj/kg
Enthalpy at inlet of expansion,
h_3= 265 kj/kg
Enthalpy at inlet outlet from expansion, h_4= 265 kj/kg
Specific volume, v =0.055 m^3 / kg

1. Cooling capacity of the unit (Q_o) =1.5 T.R. =5.275 KW
2. Refrigerating effect per unit mass, $q_o= h_1- h_4$ =405-265=140kj/kg
3. Mass flow rate (m) = Q_o/q_o=5.275/140 = 0.03768 kg/s
4. Power consumption per unit mass, $w = h_2-h_1$=452-405 =47 kj/kg
5. Coefficient of performance (COP) = $(h_1- h_4) / (h_2- h_1)$ = 140 / 47 = 2.98
6. Power consumption (W) = m x (h_2-h_1) =0.03768 x 47 =1.77 KW
7. Heat rejected in condenser (Qc) =m x $(h_2- h_3)$ =0.03768 x (452-265) = 7.046 KW
8. Displacement volume (V) = Mass flow rate x Specific volume =0.03768 x 0.055 x 3600 = 7.46 m^3 / h

Table I. Experimental results of air-cooled condenser

Sr. No.	Time duration (min)	P_1 (bar)	P_2 (bar)	COP	W (KW)	Qc (KW)	m (kg/s)	V (m^3/h)	P_2/P_1
1	0	4.4	24	2.98	1.77	7.046	0.03768	7.46	5.455
2	30	4.8	23.5	3.625	1.46	6.73	0.03638	6.55	4.896
3	60	5.2	25	3.42	1.54	6.817	0.03588	6.45	4.808
4	90	5.2	23.5	3.625	1.455	6.73	0.03638	6.55	4.519
5	120	5.1	23.5	3.625	1.455	6.73	0.03638	6.55	4.519

Table II. Experimental results of evaporative condenser

Sr. No.	Time duration (min)	P_1 (bar)	P_2 (bar)	COP	W (KW)	Q_c (KW)	m (kg/s)	V (m^3/h)	P_2/P_1
1	0	4.1	17.2	4.714	1.12	6.394	0.03197	6.68	4.198
2	30	4.4	17.6	4.79	1.1	6.375	0.03236	6.17	4
3	60	4.1	17.7	4.237	1.245	6.519	0.03276	6.84	4.318
4	90	4.2	17.4	4.378	1.205	6.48	0.03256	6.68	4.143
5	120	4.3	17.5	4.184	1.26	6.536	0.03318	6.57	4.07

3.1 SIMULATION BY COOLPACK SOFTWARE

CoolPack is a group of simulation programs used for energy assessment, designing, and development of refrigeration systems. A simulation of air conditioning system is done using CoolPack simulation software [14]. In the experimental and simulation work following assumptions are made:
Compressor isentropic efficiency =1, Degree of sub cooling =8 K,
Degree of superheating= 6K Volumetric efficiency = 0.9,
Cooling capacity= 5.275 K,
Pressure drop in evaporator =0, Pressure drop in suction line=0, pressure drop in suction line =0,Heat loss from compressor =0 %

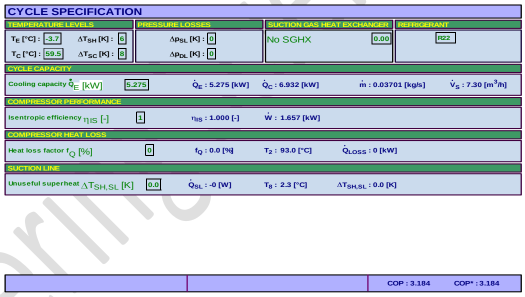

Fig. 4.Simulation of air conditioning system parameters

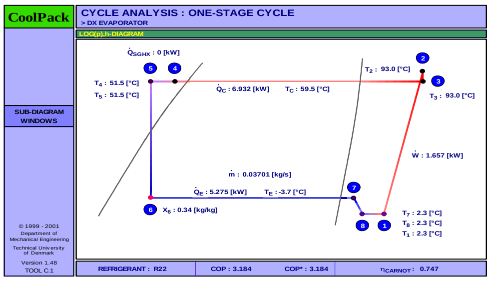

Fig. 5. Simulation of window air conditioning cycle

Table III. CoolPack simulation software results for air-cooled condenser

Sr. No.	Time (min)	P_1 (bar)	P_2 (bar)	COP	W (KW)	Q_c (KW)	m (kg/s)	V (m^3/h)	P_2/P_1
1	0	4.4	24	3.184	1.657	6.932	0.03701	7.3	5.457
2	30	4.8	23.5	3.476	1.51	6.793	0.03639	6.6	4.894
3	60	5.2	25	3.442	1.532	6.808	0.03719	6.24	4.808
4	90	5.2	23.5	3.696	1.427	6.702	0.03615	6.07	4.517
5	120	5.1	23.5	3.641	1.449	6.724	0.03621	6.19	4.606

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Table IV. CoolPack simulation software results for evaporative condenser

Sr. No.	Time (min)	P_1 (bar)	P_2 (bar)	COP	W (KW)	Q_c (KW)	m (kg/s)	V (m^3/h)	P_2/P_1
1	0	4.1	17.2	4.325	1.22	6.495	0.03236	6.88	4.198
2	30	4.4	17.6	4.47	1.18	6.453	0.03271	6.45	4
3	60	4.1	17.7	4.194	1.25	6.533	0.03295	6.95	4.318
4	90	4.2	17.4	4.357	1.211	6.486	0.03269	6.74	4.143
5	120	4.3	17.5	4.414	1.195	6.47	0.0327	6.59	4.07

3.2 VALIDATION OF THE EXPERIMENTAL RESULTS

Experimental results obtained from window air conditioning system validated from Cool Pack simulation software for same operating conditions. Percentage errors of the experimental results and simulated results shown table V and table VI using refrigerant R-22.

Table V. % error of experimental results and Cool Pack simulation software results for air-cooled condenser

Sr. No.	Time (min)	P_1 (bar)	P_2 (bar)	% Error COP	% Error W	% Error Q_c	% Error m	% Error V
1	0	4.4	24	6.41	6.82	1.64	1.21	2.19
2	30	4.8	23.5	4.29	3.31	0.93	1.07	0.76
3	60	5.2	25	0.64	0.52	0.13	0.58	3.37
4	90	5.2	23.5	1.92	1.96	0.42	0.4	7.91
5	120	5.1	23.5	0.44	0.41	6.724	1.47	6.19

From table V, it is observed that experimental results and CoolPack simulation software results for air-cooled condenser % error of COP varies from 0.44 % to 6.41 %, % error of power consumption (W) varies from 0.41 % to 6.82 %, % error of heat rejected in condenser varies from 0.13 % to 6.724 %, % error of mass flow rate varies from 0.4 % to 1.47 % and % error of displacement volume varies from 0.76 % to 7.91 %.

Table VI. % error of experimental results and CoolPack simulation software results for evaporative condenser

Sr. No.	Time duration (min)	P_1 (bar)	P_2 (bar)	% Error COP	% Error	% Error Q_c	% Error m	% Error V
1	0	4.1	17.2	8.99	8.20	1.56	1.21	2.91
2	30	4.4	17.6	7.16	6.78	1.21	1.07	4.34
3	60	4.1	17.7	1.03	0.4	0.21	0.58	1.58
4	90	4.2	17.4	0.48	0.5	0.09	0.4	0.9
5	120	4.3	17.5	5.21	5.44	1.02	1.47	0.3

From table VI, it is observed that experimental results and CoolPack simulation software results for evaporative condenser, % error of COP by varies from 0.48 % to 8.99 %, % error of power consumption (W) 0.4 % to 8.20 %, % error of heat rejected in condenser 0.09 % to 1.56%, % error of mass flow rate varies from 0.4 % to 1.47 % and % error of displacement volume varies from 0.30 % to 4.34 %.

4. RESULTS AND DISCUSSION

By using evaporative condenser in place of air-cooled condenser performance of air conditioning system improved significantly.

Table VII. Performance parameters variation by using evaporative condenser compared with air-cooled condenser

Sr. No.	Time (min)	% Increased COP	% decreased W	% decreased Qc	% decreased m	% decreased V	% decreased P_2/P_1
1	0	58.19	36.72	9.25	15.15	11.68	29.94
2	30	32.14	24.66	5.27	11.05	6.16	22.40
3	60	23.89	19.16	4.37	8.70	5.70	11.35
4	90	20.77	17.18	3.71	10.5	1.95	9.08
5	120	15.42	13.40	2.88	8.80	0.30	11.03

From above table VII shows that by using evaporative condenser coefficient of performance increased from 15.42% to 58.19 % , condenser power consumption decreased from 13.40 % to 36.72 % , heat rejected in condenser decreased from 2.88% to 9.25 %, mass flow rate decreased from 8.7 % to 15.15 % , displacement volume decreased from 0.30% to 11.68 % and pressure ratio decreased from 9.08 % to 29.94 %.

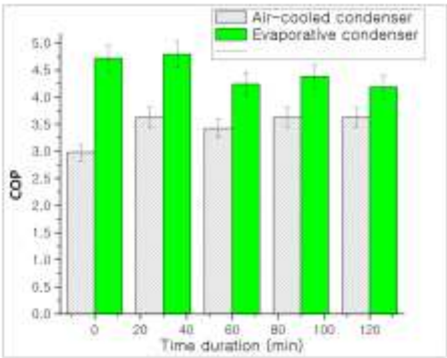

Fig. 6.Column chart shows COP of air-cooled condenser and evaporative condenser vs time duration

Figure 6 represents coefficient of performance of air-cooled condenser improve from 15.42 % to 58.19 % by using evaporative condenser due to reduce pressure ratio.

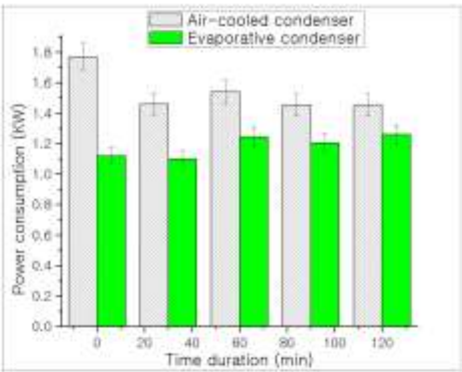

Fig. 7.Column chart shows power consumption of air-cooled condenser and evaporative condenser vs time duration

Figure 7 represents power consumption of air-cooled condenser reduce from 13.40 % to 36.72 % by using evaporative condenser due to reduce pressure ratio.

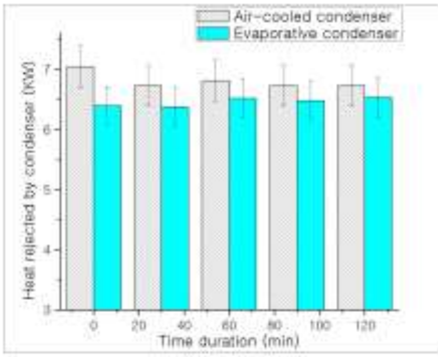

Fig. 8.column chart shows heat rejected in condenser of air-cooled condenser and evaporative condenser vs time duration

Figure 8 represents heat rejected in condenser of air-cooled condenser reduce from 2.88 % to 9.25 % by using evaporative condenser due to reduce pressure ratio.

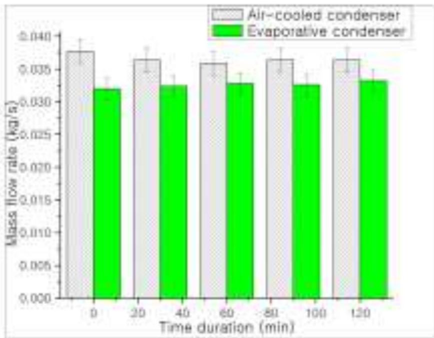

Fig. 9.Column chart shows mass flow rate of air-cooled condenser and evaporative condenser vs time duration

Figure 9 represents mass flow rate of air-cooled condenser reduce from 8.70% to15.15% by using evaporative condenser due to reduce pressure ratio.

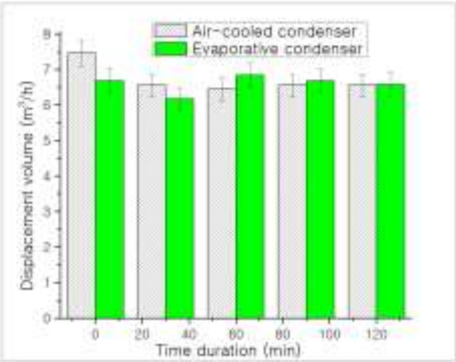

Fig. 10. Column chart shows displacement volume of air-cooled condenser and evaporative condenser vs time duration

Figure 10 represents displacement volime of air-cooled condenser reduce from 0.30% to 11.68 % by using evaporative condenser due to reduce pressure ratio.

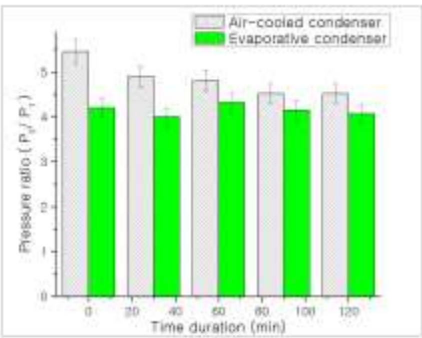

Fig. 11.Column chart shows pressure ratio of air-cooled condenser and evaporative condenser vs time duration

Figure 11 represents pressure ratio of air-cooled condenser reduce from 1.55% to 29.94% by using evaporative condenser.

5. CONCLUSION

Evaporative condenser is very useful method to improve the performance of air conditioner and to reduce energy consumption during peak demand load and torrid weather condition. In this paper experimental results of window air conditioning system using air-cooled condenser and evaporative condenser for same working condition validated by CoolPack simulation software. It is found by using evaporative condenser compared with air-cooled condenser, coefficient of performance improved from 15.42% to 58.19 % , power consumption decreased from 13.40 % to 36.72 %, mass flow rate decreased from 8.7 % to 15.15 %, heat rejection in condenser decreased from 2.88 % to 9.25 %,displacement volume decreased from 0.30% to 11.68 % and pressure ratio decreased from 1.55 % to 29.94 %.

6. ACKNOWLEDGEMENTS

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