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Experimental Analysis of Window Air Conditioner using Evaporative Cooling

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Abstract

Coefficient of performance improvement and reduction of energy consumption of an window air conditioning system when retrofitted with evaporative cooling in the condenser of window air conditioner is reviewed in this paper. The condensing unit is retrofitted with a cellulose corrugated pad. It doesn't require either any change in refrigeration system or requires minimum changes. The evaporative cooled condenser can exchange heat with the cooled ambient air cooled with evaporative cooling which is much lower in temperature than atmospheric air. By application of evaporative air cooling it is possible to exchange more heat than the unwetted exchanger. In this paper a window air conditioner is introduce by putting two cooling pads in the both sides of the air conditioner and injecting water on them in order to cool down the air before it passing over the condenser.

Keywords: **COP, Indirect Evaporative Cooling, Evaporative Condenser, Energy Saving**

1. Introduction

With impact of energy crisis and global warming many researchers have paid much attention on strategies for saving energy. Due to simplicity and flexibility air conditioner is generally used in small size in residential and commercial buildings. The condenser used in this system for heat rejection process which is generally air cooled, it seems reasonable as far as the air temperature in summer is moderate and not too high (about 40° C). But when the air temperature increase and approaches 45° C or higher as it happens in Vidharbha Regions and Middle East Countries the performance of air condenser drops down and the air conditioner work improperly. Since the temperature and the pressure of the condenser increases and the compressor is forced to work under the greater pressure ratio which result in more power consumption.

According to Chainarong Chaktranond and Peachrakha Doungsong [1] if the coil temperature of a condensing unit were raised by 1° C, the coefficient of performance of the air conditioner would drop by around 3%. If the temperature remained above 45° C for an extended period, the air conditioner would trip because of the excessive condenser working pressure. This causes the large reduction of COP means more electric power consumption for air conditioners in summer when demand for electric power is already high. In order to prevent this problem the hot air is required to be cool down before it passing over the condenser. Another problem Ebrahim Hajidavalloo [2] was reported with application of air condenser in hot weather area is related to high stories buildings. In these buildings the hot air from air conditioners of lower stories rises up and provides a hot flow field around the air conditioners of high stories. Table1 shows the year wise temperature in Vidarbha region

Year	Temperature (^{0} C)
2008	48.6
2009	48.4
2010	47.6

Table 1: Year wise temperature

2. Modification in Existing system

Chainarong Chaktranond [1] provided the guide line for energy saving in a residential sized split-type air conditioner by retrofitting condensing unit with various types of indirect evaporative cooling systems. Air stream entering condensing unit is cooled down at two positions that is in front of and within cellulose corrugated pad. Moreover injecting water into the air is divided into two type's water curtain and water spray. The evaporative cooling unit of 0.15m thick is placed in the upstream flow of air entering the condensing unit. The condensing unit comprises of cellulose pad, water pipe networks, which are located on the upper and in front of cellulose pad and a water pan at the bottom. E.Hajidavallo 2007 [2] installed two cooling pads in both sides of the air conditioner and injected water on them in order to reduce the condensing temperature in a window type air conditioner. With the cooling pads ,the water droplets, which were exchanged the heat with hot air flow, were trapped and dropped to the bottom.

Vrachopoulos2007 [3] developed an incorporated evaporative condenser, which was installed with a cooling water sprinkle network in the front. In this method water was directly sprayed into air stream. Since the air filled with water droplets was directly induced to the condensing unit corrosion problem possibly occurred on equipment. Hu and Huang 2005 [4] improved the system performance of water cooled air conditioner by utilizing the cellulose pad which was in cellulose bound cardboard structure instead of plastic packing in a cooling tower, this cellulose pad depressed the effect of surface tension on the plastic surface. This causes the contact area between air and water to be increased resulting in enhancement of heat transfer. D.Y.Goswami 1993[5] employed an evaporative cooling on existing 2.5 Ton air conditioning system by using media pad. They put four media pad around condenser and inject water from the top by a small water pump. W.Leidenfrost and B.Korenic [6] wetted the condenser of refrigeration or heat pump system makes it possible to exchange the condenser load at lower temperature. Wetted heat exchangers require less extended surfaces and can operate effectively with bare tubes only. The application of evaporative cooling in large industrial refrigeration systems were investigated by W.K.Brown [7].

3. Design of Experimentation

The main concern of applying evaporative cooling in an existing residential air conditioner with best performance and minimum side effect. There are two methods for evaporative cooling in condensers namely direct and indirect method. In direct method water is directly injected on the condenser and provides cooling effect. This method has disadvantages of including mineral deposits and corrosion of the condenser coils. Therefore, this method has rarely been used in residential air conditioners. In the indirect method water is injected on the evaporative media pad which is located in the way of air over the condenser and provides cooling effect by evaporation of water. Media pads are cellulose bound cardboard structures which are cross-fluted to increase the contact area between air and water.

The media pad should be placed where it gives the best. Since the window-air-conditioners are designed to have minimum space, therefore the limitation of space should be considered in the design. In this work two evaporative media pads, each with 3 cm thickness were installed in both sides of air conditioner to give the largest area available for cooling without increasing the total volume of the air conditioner. Hot ambient air passes over the evaporative media pads and after cooling down passes over the condenser and finally exits from back side of the condenser. A water circulation system was incorporated to spray water on the top of the media pad. It includes a small pump, tank and water spraying pipe. Energy meter was used to measure the electrical current consumption of the compressor, condenser and evaporator fan and water circulation pump.

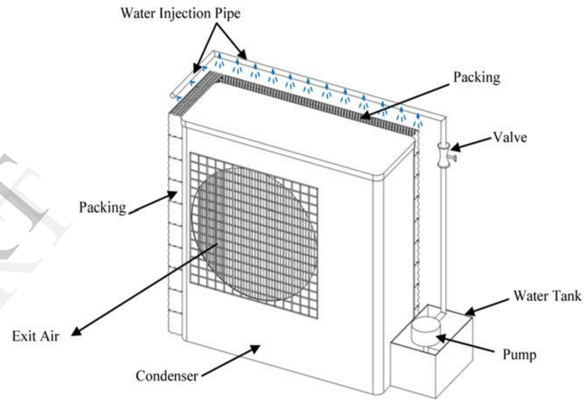

Fig 1: Schematic Diagram of Experimental Set Up

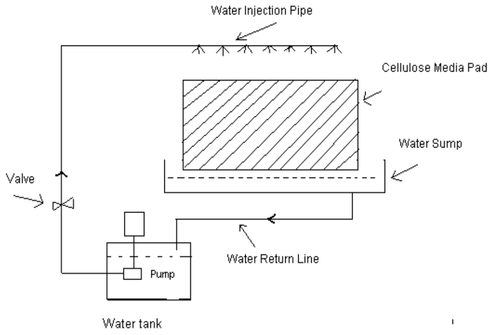

Fig 2: Water circulation diagram of evaporative media pad.

4. Experimental Analysis

Case I:

T	E	P_1	P_2	P_3	P_4	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Conventional Cycle														
00	61.0	26	25	6.2	5.5	92.5	48.4	15.3	22.4	42.3	66.7	43.5	23.5	44
20	61.7	27.2	26.5	6.7	5.56	95.7	52.5	17.1	24.6	42.8	67.4	43.5	22.7	44
40	62.5	28	27	6.9	5.62	102	53	18.9	25.3	43.7	68.5	43.7	21.3	44
60	63.1	28.5	27.5	7.3	5.7	107	53.9	18.9	27.9	44	70	44	20.6	44
Evaporative cycle														
00	59.1	24.8	21.5	6.2	4.3	85	44.5	16.8	25.9	43	59.5	43	18.5	44
20	59.9	24.4	21.9	6.2	4.3	83	44.1	16.5	25.2	27.8	58.9	43	18.2	44
40	60.8	24.1	22.6	6.2	4.2	79	43.1	16.9	24.8	28	58.2	43	18	44
60	61	23.9	22.8	6.1	4.1	77	43.9	15.1	24.2	28.1	56.5	42.8	17.6	44

Table 2: Experimental reading for Conventional Cycle and Evaporative cycle

Case II:

T	E	P_1	P_2	P_3	P_4	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Conventional Cycle														
00	57.0	25	24	5.8	4.7	91.1	49.4	16.1	24.9	42.5	62.4	42.8	18.4	43
20	57.9	25.9	25..3	5.9	4.8	94.3	51.5	16.9	25.4	42.6	64.8	42.9	19.1	43
40	58.4	26.8	25.9	5.9	4.8	98.3	51.9	17.1	25.9	43	65.4	42.9	19.9	43
60	59.1	27.6	26.3	6.0	4.9	102	52.8	17.2	26.4	43	66	43.1	19.5	43
Evaporative cycle														
00	59.1	24.8	21.5	6.2	4.3	85	44.5	16.8	25.9	43	59.5	43	18.5	43
20	59.9	24.4	21.9	6.2	4.3	83	44.1	16.5	25.2	27.8	58.9	43	18.2	43
40	60.8	24.1	22.6	6.2	4.2	79	43.1	16.9	24.8	28	58.2	43	18	43
60	61.0	23.9	22.8	6.1	4.1	77	43.9	15.1	24.2	28.1	56.5	42.8	17.6	**43**

Table 3: Experimental reading for Conventional Cycle and Evaporative cycle

T – Time in (minute)
E – Energy meter reading (kwh)
P – Pressure (kg/cm^2)
t – Temperature (^0C)
P_1 – Pressure at compressor outlet
P_2 – Pressure at condenser outlet
P_3 – Pressure at Expansion outlet
P_4 – Pressure at Evaporator outlet
T_1 – Temperature at compressor outlet
T_2 – Temperature at condenser outlet
T_3 – Temperature at expansion outlet
T_4 – Temperature at evaporator outlet
T_5 –Temperature after passage of air through evaporative pad
T_6 – Condenser outlet backside air temperature
T_7 – Evaporator inlet air temperatue
T_8 – Evaporetor outlet air temperatue
T_9 – Ambient air temperature

5. Experimental results and discussions

Many preliminary experiments were performed to prepare the set up for getting reliable data. In order to have a basis for comparison and also to specify the effect of evaporative cooling on the air conditioner, each experiment was performed in two consequent stages. In the first stage, conventional air conditioner was used in the experiment without using media pad and the data were recorded after steady state condition was established. Then, the air conditioner was turned off and the condenser of air conditioner was retrofitted by evaporative cooling very fast and the second stage of the experiment was performed. The time difference between two stages was small (about one hour.), so the weather condition for two experiments was the same. In all experiments the data were recorded after steady state condition was established and the properties of refrigerant and air remained constant.

Many tests were performed to determine the effect of evaporative cooling on the performance of air conditioning system. The results of an experimental run (Case I) are shown in Table 2. and the results of an experimental run (Case II) are shown in Table 3.Fig. 3 shows the results on P–h diagram for Case I and Fig. 4 shows the results on P–h diagram for Case II.

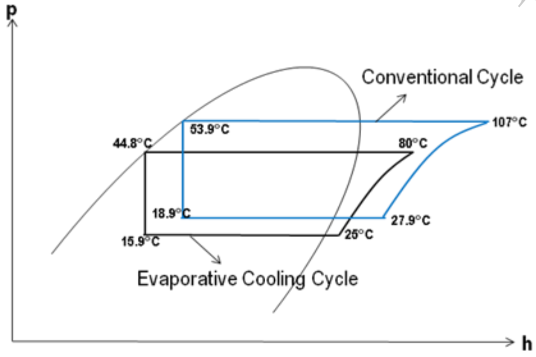

Fig: 3 The P–h diagram of conventional and evaporative cooling cycle (Case I).

As shown in Fig 3. by applying evaporative cooling the pressure in the condenser reduced from 27.5 kg/cm^2 to 23.5 kg/cm^2 which shows 30% reduction but the pressre in the evaporator reduced from 5.7 kg/cm^2 to 4.4 kg/cm^2 which shows 15% reduction. Therefore pressure ratio across the cycle reduces from 4.5 to 3.25 which shows 20% reduction. This reduction is an indication of power reduction in the system. Also as it shown in Fig 4 the condenser temperature in the retrofitted system reduced about 10^{0}C while evaporator temerature reduced about 5^0 C shown in Fig 5 which is another indication of reduction in pressure ratio of a cycle.

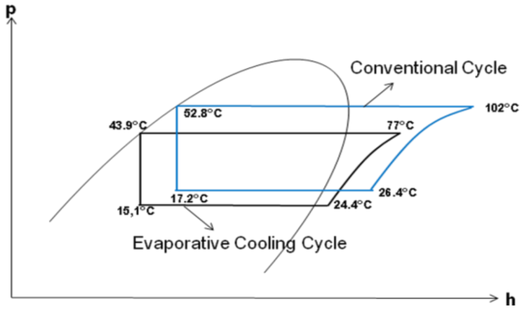

Fig : 4 The P–h diagram of conventional and evaporative cooling cycle (Case II).

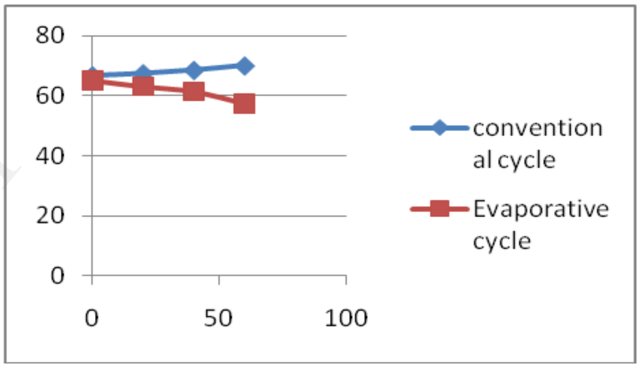

Fig : 5 Condenser outlet air temperature

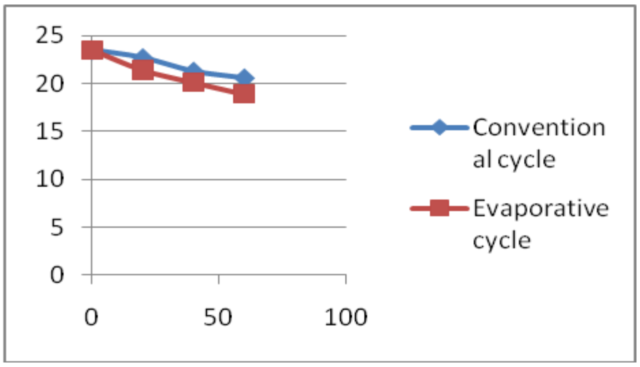

Fig 6: Evaporator outlet air temperature

6. Calculation and results

In order to calculate the cooling capacity, refrigerant effect and COP, it is required to specify thermodynamic properties of refrigerant at different sections of the cycle based on the experimental results. Tables 4 and 5 show the thermodynamic properties of refrigerant for conventional and evaporative runs respectively based on data from Van Wylen and Sonntag for case I. and Tables 6 and 7 show the thermodynamic properties of refrigerant for conventional and evaporative runs for Case II.

Thermodynamic Properties of R-22
Case I:

Evaporat exit	Compre exit	Conde exit	Capilla exit	Unit
T_1= 27.9	T_2= 107	T_3= 53.9	T_4= 18.9	°C
P_1= 5.7	P_2= 28.5	P_3= 27.5	P_4= 7	Kg/cm^2
H_1= 432	H_2= 462	H_3= 280	H_4= 280	KJ/kg

Table 4: For Conventional Cycle

Evaporat exit	Compre exit	Conde exit	Capilla exit	Unit
T_1= 25	T_2= 80	T_3= 44.8	T_4= 15.9	°C
P_1= 4.4	P_2= 24.3	P_3= 23.5	P_4= 6.3	Kg/cm^2
H_1= 430	H_2= 450	H_3= 260	H_4= 260	KJ/kg

Table 5: For Evaporative Cycle

For Conventional Cycle:

Power Consumption= Wc = V I=2.1kw
Mass Flow Rate= m = Wc/h_2-h_1; m=0.0105kg/sec
Refrigerant Effect = q_c= h_1-h_3=152kj/kg
COP = h_1-h_3/h_2-h_1=7.6

For Evaporative Cycle:

Power Consumption= Wc+Wp = V I=1.8 Kw
Mass Flow Rate= m = Wc/h_2-h_1; m=0.0119kg/sec
Refrigerant Effect = q_c= h_1-h_3=170kj/kg
COP = h_1-h_3/h_2-h_1=8.5

Thermodynamic Properties of R-22
Case II:

Evaporat exit	Compre exit	Conde exit	Capilla exit	Unit
T_1= 26.4	T_2= 102	T_3= 52.8	T_4= 17.2	°C
P_1= 4.9	P_2= 27.6	P_3= 26.3	P_4=	Kg/cm^2
H_1= 428	H_2= 458	H_3= 262	H_4=6 262	KJ/kg

Table 6: For Conventional Cycle

Evaporat exit	Compre exit	Conde exit	Capilla exit	Unit
T_1= 24.2	T_2= 77	T_3= 43.9	T_4= 15.1	°C
P_1= 4.1	P_2= 23.9	P_3= 22.8	P_4= 6.8	Kg/cm^2
H_1= 425	H_2= 450	H_3= 255	H_4= 255	KJ/kg

Table 7: For Evaporative Cycle

For Conventional Cycle:

Power Consumption= Wc = V I=2.1kw
Mass Flow Rate= m = Wc/h_2-h_1; m=0.007kg/sec
Refrigerant Effect = q_c= h_1-h_3=166kj/kg
COP = h_1-h_3/h_2-h_1=5.92

For Evaporative Cycle:

Power Consumption= Wc+Wp = V I=1.9 Kw
Mass Flow Rate= m = Wc/h_2-h_1; m=0.00791kg/sec
Refrigerant Effect = q_c= h_1-h_3=170kj/kg
COP = h_1-h_3/h_2-h_1=7.08

7. Conclusions

The application of evaporative cooling in the small size refrigeration system was emphasized for regions of very hot weather condition. A novel design for employing indirect evaporative cooling system in a window-air-conditioner was introduced. The potential of commercialization of this design is very high and it could also be easily applied on existing air conditioners. The performance of air conditioner was experimentally investigated with and without media pad evaporative cooling on the condenser and it is found that.

- By Applying Evaporative cooling pressure in the condenser reduces to 20%
- Pressure in the evaporator reduces 12%
- Pressure ratio across the cycle reduces 18%
- This pressure reduction is the indication of power reduction in the system
- COP increases

8. References

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