American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-7, Issue-12, pp-277-285
www.ajer.org
Research Paper Open Access

Evaluation of Energy Saving in a Package Air Conditioner with Optimum Atomized Water Spray Type Evaporative System. (Case Study: A Villa in Kuwait)

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ABSTRACT : *This research work is based upon practical experiment aims to evaluate the energy saving in a package unit-type air conditioner. This was done by carrying out a comparison between two identical five-tons package-unit air conditioners, one is ordinary package unit-type air conditioner and the other typical unit was modified with optimum water usage sprayers as well as water source, pump and nozzles to spray water on the tubes of its condenser. Both package units were subjected to the same exactly operation and environmental conditions and cool the second and third floors, which have the same heating load, in a four floors villa in Kuwait. The power consumption and cooling capacity obtained from both units are monitored in the time and compared. Results of the comparison show that the electrical power consumption and coefficient of performance (COP) significantly depend on the ambient conditions due to effects of condensing pressure and temperature. When the ambient temperature rises, the electrical consumption becomes higher, while the COP becomes lower. However, using the evaporative cooling system, which is used to decrease the temperature of air entering the condenser, the system performance is enhanced considerably. Finally, it can be concluded that by using the evaporative cooling systems, COP is improved by around 42.2%, and electrical power consumption is approximately reduced by 14.55%. A literature review of the previous work is also introduced in this paper.*

KEYWORDS *Air Conditioning; Packaged air conditioner; R407C; Evaporative cooling; Energy saving*

Date of Submission: 18-12-2018 Date of Acceptance: 31-12-2018

I. INTRODUCTION

The strategies for energy saving become the main essential concern of the whole modern world specially with impact of energy crisis and global warming. It is reported that refrigeration and conditioning systems using mechanical vapor compression represents are about 15% of the worldwide consumed electricity, in Kuwait, this percentage is raised up to 70% for air conditioning systems. Thus, energy saving and environmentally friendly systems in this sector are very important. The power consumption concern increased much more if the air-cooled condensers work in area with very high ambient temperature (between 45-50^{o}C;113^{o}F-122^{o}F), as it happens in state of Kuwait specially in hot summer. In this area, the temperature and pressure of the air-cooled condenser will have increased considerably. This causes an increase in pressure ratio which increases the power consumption of the air conditioner. Also, when the pressure increases, the pressure limit switch in the control system will shut down the compressor. The increase of the condenser temperature will decrease the cooling capacity of the cycle due to the reduction of liquid content in the evaporator. So, the high pressure and temperature of the air-cooled condenser will decrease the performance of the air conditioner considerably. In the tropical climate countries, such as Kuwait, many research studies are heading to energy saving specially to the electrical energy consumption of the air conditioning systems which are used almost all over the year (almost 9 months a year). Generally, the conventional package unit-type air conditioners widely used in small and medium size buildings, e.g. residences, offices, and schools due to its simplicity and flexibility. Condenser as a part of the conventional package unit-type air conditioner is mainly used to condense the high-pressure refrigerant gas coming from the compressor. In addition, condenser performance depends on the heat transfer between refrigerant inside the coils and the ambient airflow. The operation temperature of air-conditioning units has a significant effect on the coefficient of performance (COP) of air conditioners (Chow et al 2002 [1], [2] reported that if the on-coil temperature of a condensing unit were raised by 1OC, the coefficient of performance (COP) of the air conditioner would drop by around 3%).In addition, if this temperature remained above 45^{O}C for an extended period, the air conditioner would trip because of the excessive condenser working pressure.

This research study aims to improve the performance of air conditioning system and saving the power consumed by optimal water spray into the condenser cooling air to reduce the condensing temperature and hence reducing the compressor power which led directly to increasing the coefficient of cycle performance (COP). The used water spry is got from cold bled water in the conditioned space without any external source of water.

II. LITERATURE REVIEW

In this literature review, many researches discussed the same concept of spraying water on the refrigerant condenser. May et al. [3] did research in Kuwait temperatures from 39^{o}C to 45^{o}C, using three different methods of pre-cooling the condenser air, the cooling pad, the cooling mesh and shading. The used Psychrometric testing room. They reached a drop in the power consumption from 8.1 to 20.5%, and the cooling load increased from 6.4 to 7.8% by using cooling pad and cooling mesh, which resulted in an increase in the COP of the units by 36-59%.

An evaporative cooling on the condenser of window-air conditioner in ambient temperature of 50^{o}C was done by Ebrahim [4], where a new design was introduced and experimentally investigated. They used two cooling pads in both sides of the condenser and water was injected on them to cool down the air before it passed over the condenser It concluded that thermal characteristics of new system were improved, and power consumption was decreases by about 16% and the COP increases by about 55%.

Technology Test Centers, Southern California Edison, in 2009 wrote a final report [5], where the evaporative cooled condenser of split unit produced the same cooling capacity at lower power consumption. Also, they concluded that there is an increased in water consumption at hotter and dryer climate zone conditions as well as energy saving.

In a split-type air conditioner, which was using various types of evaporative cooling system Chainaronget al. [6], did a research to evaluate the energy saving. They retrofitted the condensing unit with a cellulose corrugated pad, water sprayers, a water source and a pump. It was found that when ambient temperature was raised by 1^{O}C, electrical power energy consumed increased by about 4%, and due to high contact surface between water and air-stream, the power consumption was decreased by about 15% and increases the COP up to 45%.

Raminet al. [7] carried out experiment tests which proved that the evaporative condenser-type air conditioner operated with better efficiency than air cooled system in all climate conditions. The water consumption found under Air-Conditioning, Heating and Refrigeration Institute-Test A and conditions of 95°F DB and 75°F WB were purged 0.59 gal/hr/ton of water each hour and evaporated 1.86 gal/hr/ton for a total water consumption of 2.45 gal/hr/ton.

From Thermodynamic point of view, Zhonghuaet al. [8], studied the heat transfer effect of different condenser types, searching for the condenser which has best heat transfer efficiency and energy saving. It was shown that spray evaporative condenser refrigerant temperature difference and the inlet and outlet air enthalpy difference of the condenser are larger than conventional air-conditioning condenser. Also, the fan speed was lower than others, moreover the compressor also reduces the work pressure, so improved the split-type air-conditioning condenser heat transfer and reduced water and energy consumption when the condensers are at runtime.

Aglaweet al. [9], did a research on window air conditioning where it was found that the air conditioner performance was experimentally investigated with and without media pad evaporative cooling over the condenser and it was found that by applying evaporative cooling the pressure in the condenser reduces to 20%, and the pressure in the evaporator reduces 12%. Accordingly, the pressure ratio across the cycle reduces by 18%, this pressure reduction gives an indication about the power reduction in the system and the increase in COP.

Many different methods like using cooling media, water mist spraying was introduced by Biranganeet al. [10], where it was found that air cooled condensers performance can be improved up to some extent. Many other different innovative methods for evaporative cooling can still be developed in the future.

Manojet al. [11], did a research to investigate the performance of the condenser of split type air conditioning system using evaporative cooling and it was found that the pressure ratio across the cycle reduced, and the reduction of pressure ratio leaded to a power reduction of the system. Also, the power consumption decreased, cooling capacity and coefficient of performance were increased.

In subtropical regions, Najim [12] did a research by applying mist pre-cooling to air-cooled air conditioner operation. The cooling effect was increased, and the power consumption was decreased when the air conditioner operates in a hot outdoor environment. Finally, it can be found that the power consumption of the compressor was decreased by 14.6 % and the cooling capacity was decreased by 17.3%, with decreasing the temperature of air entering the condenser, the COP of the air conditioner was increased by 31.4%.

Tianweiet al. [13] performed an experimental research of air conditioning system using evaporative cooling condenser. It was found out that the COP increased. Also, the saturation temperature drops through the condenser increased from 2.4^{o}C to 6.6^{o}C, as well as an increase of the mass flow rate of refrigerant that goes to evaporator, and consequently the COP increased from 6.1% to 18%, as well as a reduction up to 14.3% on the compressor was also achieved.

Sreejith et al. [14] investigated experimental research on the effect of water-cooled condenser in a household refrigerator air-cooled and water-cooled condenser, the experiment was done using HFC134a as the refrigerant. The performances of both were compared for different load conditions. It was found that the refrigerator performance had improved when water-cooled condenser was used instead of air-cooled condenser on all load conditions. Water-cooled condenser reduced the power consumption when compared with the air-cooled condenser between 8% and 11% for various loads conditions.

Mohammed et al. [15], did a research in areas with very hot weather conditions (50 to 60°C), and it was found that, at high ambient temperature, all types of modifications for enhancing condenser performance have been found to produce an obvious drop in outlet temperature from evaporator as compared to system without modifications. Also, cost benefit analysis in terms of life cycle cost, net present value, cost-benefit ratio, and payback period have been done, the cooling capacity was enhanced, and the power consumption was reduced at the same time.

By using air cooled condenser with water atomization, Alotaibi, et al. [16] introduced an experimental research on a design of evaporative cooling condenser of air -conditioning. An actual air conditioner was used to test the innovation by using a mist system to cool down the ambient air before it was passing over the condenser. The experiment was carried out for two similar rooms with the same initial conditions, and both equipped with typically brand new mini split air conditioning units having the same size and type. It is found that thermodynamic characteristics of evaporative cooling condenser are considerably improved. The power consumption decreases by about 11% and the COP increases by about 13%.

Islam et al. [17] perform experimentally and numerically study on an air-conditioning unit with evaporative cooled condenser coil. The experimental results showed that the COP increases by about 28% compared to the conventional unit.

Kamlesh et al. [18], presents a broad review of evaporative cooled condenser used in residential and commercial cooling systems. It was concluded that evaporative cooled condenser increases the heat rejection process with the cooling effect of evaporation and therefore improve coefficient of performance. It was found that by using evaporative cooling condenser, the energy consumption decreased to 20 % and COP increased to 50%.

Martinez et al. [19] carried out experimental research on the energy performance of a split air-conditioning by using variable evaporative cooling pads thickness coupled to the condenser. The impact of the different cooling pads on the overall performance of the air-conditioning system is experimentally determined by measuring the air flow conditions and the energy consumption of the overall air-conditioning system, including both the condenser fan and the feed water recirculation pump of the cooling pads. It was found that the best overall COP is obtained by adding a cooling pad thickness of to 100 mm. At that point the compressor power consumption is reduced by 11.4%, the cooling capacity is increased by 1.8% and finally the COP is increased by 10.6%.

Adel et al. [20]. performed research on a small air conditioning system by means of direct evaporative cooling method using wet pads. A setup of cooling system is designed to simulate extremely hot weather where the dry bulb temperature (DBT) of 55◦C. The results showed significant increase to the entire A/C system performance where the refrigeration capacity is increased in the range of 5% to 7.5% and there is 0.12A to 0.16A electrical current reduction for each temperature degree reduction.

Ndukaife et al. [21] did experimental investigation of the reduction of energy consumption in a split air-conditioning system employing evaporative cooling by varying the pad thickness from 5 cm to 15 cm in steps size of 5 cm. The results obtained showed that up to 44% increase in COP, and a 20% decrease in power consumption. Additionally, the COP increased by about 4% for every 1°C drop in refrigerant condensing temperature.

III. TEST FACILUTY AND EXPERIMENTAL APPAPATUS

III.(A) Basic Experimental Layout

This research work is based upon the comparison between two identical package units. Both are subjected to the same exactly operation and environmental conditions and in practical are used to cool the second and third floors, which they have the same heating load, in a four floors villa in Kuwait. One packaged unit is modified by adding atomized spray water system. A ball float control fresh water tank inside the conditioned space is used to gain a reduction in spray water temperature. Atomize spraying this room temperature water is done by using DC water pump of 100 W with maximum flow rate 0.065 m3/min, a flood/water sensor in the water spray sump beneath the condenser is used to keep the optimum water consumption. The other package unit-type air conditioner is a conventional type without any modifications. Both air conditioners have the same specifications. All the data taken during the experiment were done for both air conditioners operation in the same time.

The Specification of each package unit-type air conditioner (SKMAIRCON [22]) are as follows:

- Cooling Tonnage is nominal 5 tons, Actual Capacity 53.56 MBH (15.7 Kw), Capacity ratings based on evaporator entering air temperatures of 80/67 ºF (26.7/19.4ºC) dry bulb/wet bulb and condenser entering air temperature of 115ºF (46ºC). Total sensible cooling capacity 40.1 MBH (11.8 Kw), Compressor, total electricity power input PI 5.4 Kw, hermetic scroll compressor.
- Condenser coil type, air cooled, 3 rows 16 FPI (1.6mm) fin spacing, Aluminum Fins, Copper Tubes. Condenser Fan, two propellers, direct drive 960 RPM. Air Flow Rate, 8540 cfm (4030 L/s). Condenser motor, totally enclosed air over, 4 poles or 6 poles, 0.275/2 Kw.
- Evaporator Coil, direct expansion, 14 FPI (1.8mm) fin spacing, aluminum fins, face area, 4.6 ft2 (0.4 m2).
- Evaporator Fan, centrifugal double inlet double width belt drive, air flow rate 2000 cfm (944 L/s).
- Evaporator Motor, totally enclosed fan, Class-F insulation, 4-pole, 0.55 Kw.
- Refrigerant: (R-407C), operating charge, 7.6 Ibs (3.5 kg).
- Electric power supply, 415V/3PH/50Hz.

Figure (1) shows the basic components layout of the modified package unit-type air conditioner used in the test, the basic idea shown in the figure is that a fresh water tank kept inside the conditioned space and a variable discharge pump (variable speed DC Motor) to inject the optimum amount of room temperature water to the condenser of the package unit-air conditioner. Two water filters are used before and after the ball float fresh water tank to insure clean spray water.

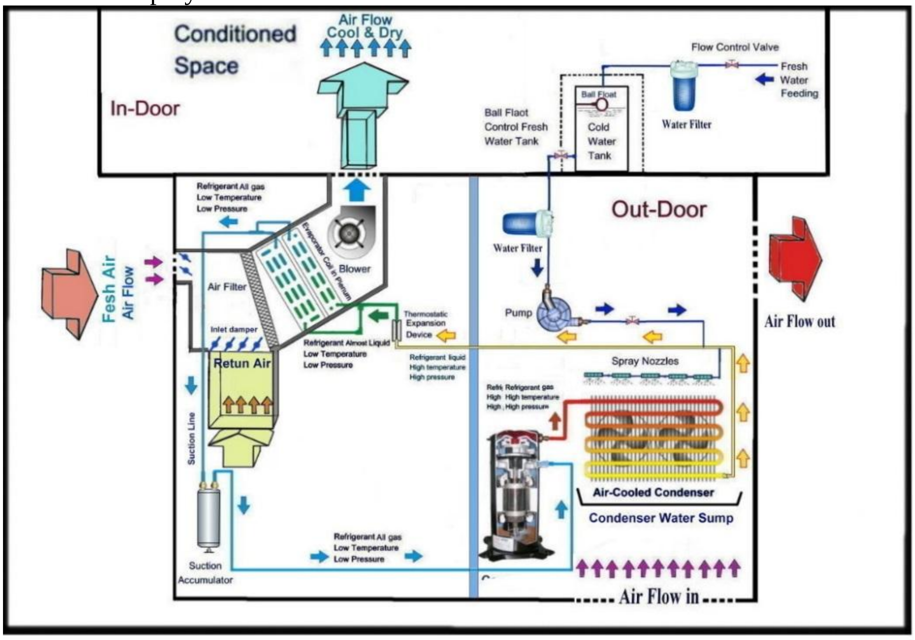

Figure 1: The layout components of experimental work

III. (B) Basic Instrumentationand Equipment Installation

Figure (2) shows the sensors layout which are installed in the modified package unit-type air conditioner used in the test of this research work. Flood/ water sensor is installed in the spray water sump beneath the condenser for two reasons, first to prevent the accumulation of excess water in the spray water sump and to control the amount of pumped spray water to be an optimum amount consumed. Flood/ water sensor

gives signal to control the amount of sprayed water by the pump. Condenser tube surface temperature sensors (RTD -6 points measured) are also control proportionally the water flow of the pump to maintain enough amount of spray water on the condenser.
Sensors setup for both packaged units where the temperature, pressure, and flow rate measured according to the following arrangement as given in Figure (2):

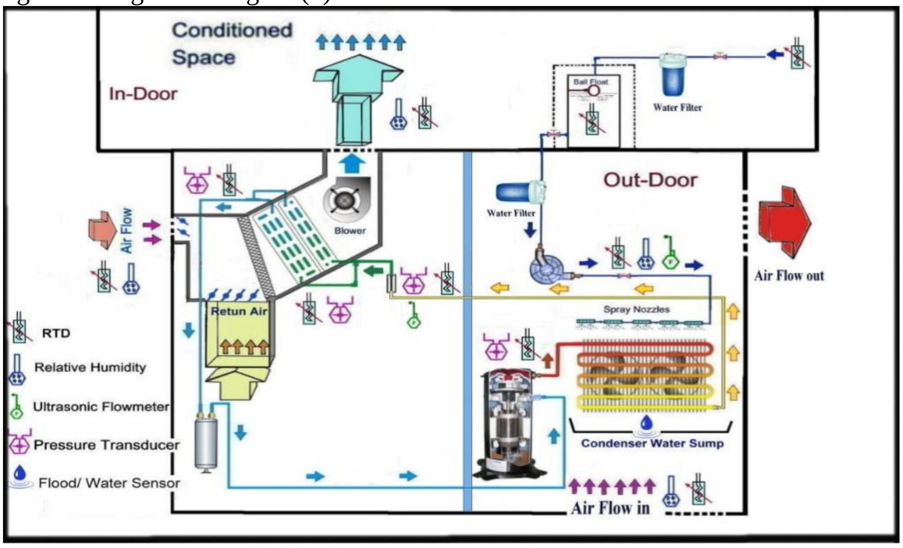

Figure 2: The Sensors arrangement layout components

1- Resistance Temperature Difference (RTD): To measure the temperature at different points such as shown in Figure (2); temperature at the inlet of water feeding, temperature inside cold-water storage tank, temperature after water spray pump, (6-point at the condenser tube surface), temperature before and after thermal expansion valve, conditioned space temperature, all air flow in temperatures, temperature of the refrigerant at suction and discharge lines of compressor.
2- Ultrasonic flowmeters: to measure refrigerant liquid flow rate before the thermal expansion valve for both packaged units. As well as water flow rate after the water spray pump
3- Pressure transducer: to measure pressure at the suction and discharge points of the compressor, the pressure before and after the thermal expansion valve, before and after the refrigerant condenser coil.
4- Relative humidity: to measure the humidity of air flow before and after the refrigerant condenser coil, humidity inside the conditioned space, all air flow admitted to (fresh air and condenser cooling air) the package unit.
5- Wattmeter: to measure the total consumed power supplied to the package unit-type air conditioner in both cases (2- points). 6- Data acquisition system: OMEGA 1-MHz, 16-Bit USB Data Acquisition Modules OMB-DAQ-3000 Series (16+48 channels) with the most advanced characteristics. It includes DaqView Software for instant set-up, real-time viewing, data logging and Frequency Domain Analysis, compatible with Windows 10. And comprehensive drivers for DASYLab, LabVIEW and DaqCal Software. The data acquisition system is connected to laptop computer for the analyses.

All data's readings from the above-mentioned sensors were fed directly to the Data acquisition system at the same time and then analyzed instantaneously by the software program. The data acquisition system was programed to process all readings from all installed sensors every 10 minutes during the test.

IV. TEST PROCEDURES

The experimental work is carried out in a Villa in Kuwait (2nd and 3rd floors in a 4- floors Villa) and all test measurements are taken for both package units at the same time and all the test days. All the taken reading are given to the data acquisition system of (16+48 channels) with software connected to laptop for the analyses. The test is carried out from 11:00 am to 6:00 pm in interval of 10 min during the hot season of May, June, July, August, and September in Kuwait.

IV. (A) Results and Discussions

The experiment results are discussed and analyze according to data acquisition outcomes. The first discussion is concerned with the analysis of the dry bulb air temperature difference across the condenser in three different temperatures (40^{o}C, 45^{o}C and 50^{o}C) taken for two hours a day for both compared package units (with and without water spray). The experiment is carried out for chosen days where the temperatures satisfy the above selected temperatures. Figures (3), (4) and (5), show the results of the air temperature difference across the condenser. In the case where the inlet air ambient temperature was 40°C, the outlet air dry bulb temperature drops by about 25%, while in case where the inlet air ambient temperature was 45°C, the outlet air dry bulb temperature drops by about 30.4%, but in the case where the inlet air ambient temperature was 50°C, the outlet air dry bulb temperature drops by about 33.2%. From these results, it has been observed that by spraying water across the condenser, it is cooled and highly decrease the dry bulb temperature of the outlet air specially in higher inlet air ambient temperatures. Therefore, the spray of water on the condenser not only decrease the outlet dry bulb air temperature, but also increase the performance of the refrigerant cycle and reflected to the COP of all cycle.

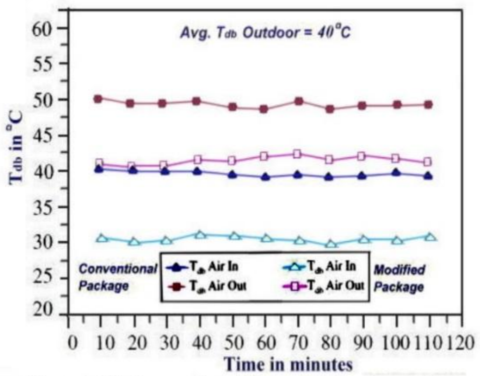

Figure 3: The temperature difference across the condenser (ambient inlet air temperature 40°C).

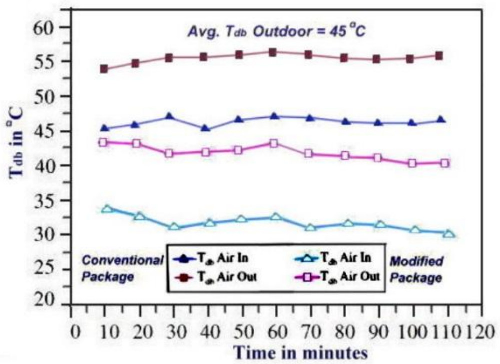

Figure 4: The temperature difference across the condenser (ambient inlet air temperature 45°C).

Figure (6) gives the dry bulb temperature of inlet and outlet air across the condenser measured for twelve hours from 6:00 am to 6:00 pm during a day of mean maximum temperature was 48°C and the mean minimum temperature was 40°C. From the figure, it is observed that the effect of sprayed water on the condenser increases as much as the temperature increases. The experiment results shows a great effect of sprayed water on the condenser cooling and concequently on the performance of the package-unit air conditioning system. The results of an experimental run are shown on Table(1) and Figure (7), where the 4-cycles of air conditioning processes (Compressor- Condeser- Expansion- Evaporator) are draw on P-h diagram for both conditions (with and without sprayed water). As shown in the figure as P-h diagram, by applying the sprayed water to the condenser cooling, pressure in the condenser reduced from 390 psia to 280 psia which shows 28.2% reduction, but the pressure in the evaporator reduced from 62 psia to 56 psia which shows a 9% reduction. Therefore, pressure ratio across the cycle reduces from 6.05 to 4.91 which has 18.8 % reduction. This reduction is an indication of power reduction in the system. With respect to the condenser temperature in the cycle, it is reduced from 115°F to 95°F which shows 17.4% reduction, while the evaporator temperature reduced from 39°F to 37°F which shows 5.1% reduction, this is another indication of reduction in pressure ratio of cycle.

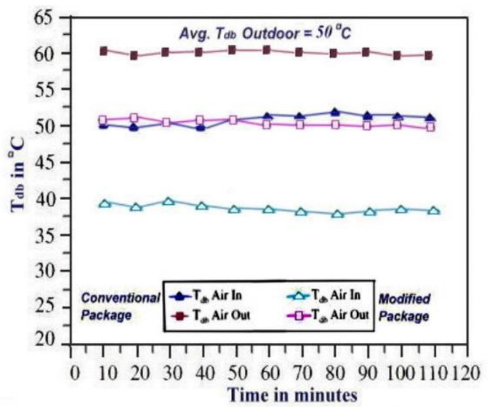

Figure 5: The temperature difference across the condenser (ambient inlet air temperature 50°C).

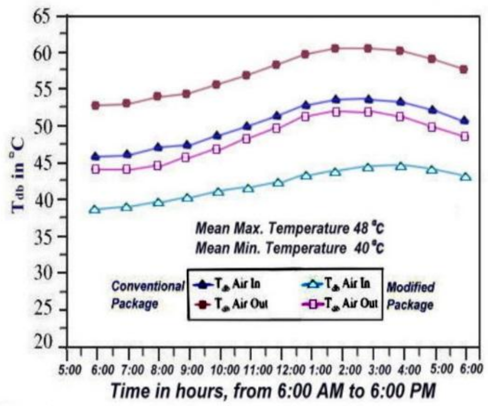

Figure 6: The temperature difference across the condenser during 12 hrs. a day.

Table (1): Experiment Result

Parameter	Without Sprayed water	With Sprayed water
Ambient dry bulb tempreture	115 ºF	115 ºF
Ambient wet bulb temperature	75 ºF	75 ºF
Compressor exit temperature	230 ºF	170 ºF
Condenser exit temperature	115 ºF	95 ºF
Evaporator exit temperature	58 ºF	55 ºF
Expansion exit temperature	39 ºF	37 ºF
Compressor exit pressure	390 psia	280 psia
Condenser exit pressure	375 psia	275 psia
Expansion exit pressure	62 psia	56 psia
Evaporator exit pressure	58.6 psia	53psia

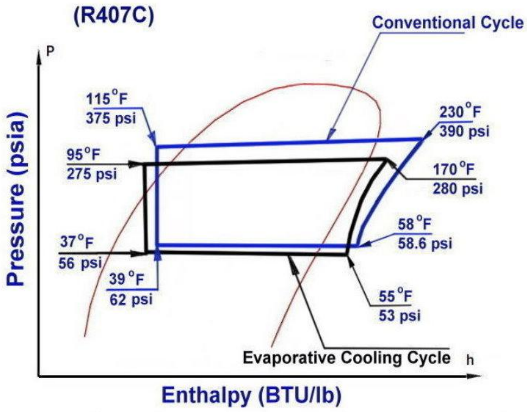

Figure 7: The Refrigeration Cycles for Conventional and spray water evaporative Cooling.

In order to calculate the cooling capacity, refrigerant effect and COP, the thermodynamic properties of refrigerant at different sections of the cycle based on the experimental results for conventional and sprayed water are given in Table (2). From Table (2), it is clear that the the enthalpy at the compressor suction is reduced by 7.2%, the enthalpy at the compressor exit is reduced by 9.8%. Mass flow rate increase about 5.2%, and cooling capacity increased about 9%. the heat power of the compressor is reduced by 23.5%, the total electric power obtained by the wattmeters for both conventional and spray type evaporators at the same time shows a reduction by about 14.55%, this power incolouded the power of the condenser and the evaporator fan motor as well as the water pump motor. The COP which is the most important parametr increase about 42.2%, which indicate that by employing spray water on the condenser, not only power consumption decreases, but also cooling capacity increases.

IV. (B) Spray Water Consumption

This experiment was performed for room temperature bled water mass flow 0f 2.95≤ mb ≤ 12.25 gal/hr, the inside conditioned space temperature is almost constant with in (24^{o}C-75^{o}F), While the ambient dry bulb tempreture is (from 30^{o}C-86^{o}F to 50^{o}C-122^{o}F) during a day time. Taking advantage of the evaporative cooling process using sprayed water is beneficial to energy efficiency. The lowered saturated refrigerant condensing temperature due to wet bulb temperature results in a significant benefit of reduced energy consumption. Water consumption versus water availability, however, may be an issue in areas where evaporatively-cooled condensing units perform optimally. To keep the rate of consumed sprayed water in an optimum level, a Flood/water sensor is used to control the amount pumped spray water according to the condenser temperature. Figure (8) shows the difference between the amount of consumed sprayed water in constant and variable rates. By using the Flood/water sensor, the amount of water saved is a function of wet bulb temperature, staring from (from 30^{o}C-86^{o}F to 50^{o}C-122^{o}F), the saving amount of water is varied between 65.3% at 86^{o}F, 32.6% at 104^{o}F, 18.4% at 113^{o}F, and 4% at 122^{o}F.

Table (2): Thermal and Electrical Result

Parameter	Without Sprayed water	With Sprayed water	variation
h1	125 BTU/Ib	116 BTU/Ib	-7.2%
h2	149.9 BTU/Ib	135 BTU/Ib	-9.8%
h4	53 BTU/Ib	47 BTU/Ib	-11.3%
m°	13.5 Ib/min	14.2 Ib/min	+5.2%
q	72 BTU/Ib	75 BTU/Ib	+4.2%
w	24.6 BTU/Ib	19 BTU/Ib	22.7%
Q	977 BTU/min	1065 BTU/min	+9%
W	352.5 BTU/min	269.8 BTU/min	-23.5%
Electrical Total power	6.53 KW	5.58KW	-14.55%
C.O.P	2.77	3.94	+42.2%

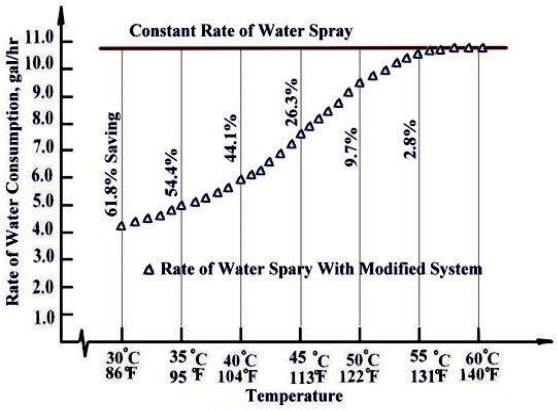

Figure 8: Comparison Between Constant and Variable water spray rates.

V. CONCLUSION

From the literature survey, must of the researches works concerning the evaporative spray water were carried out on windows and/or split units air conditioning systems. This research work is distinguishing itself that it uses two identical package air conditioning units of actual installation in a Vela in Kuwait, as well as improving a way to optimize the amount of spray water on the condenser specially when the ambient temperature is less than 115°F.

By applying spray room temperature water evaporative cooling system to the condenser unit in the package-unit type air conditioner, the air entering condensing unit is cooled to a lower temperature which causes the power consumption by compressor to lower, and the refrigeration capacity to be higher, resulting in enhancement of COP. In addition, evaporating cooling systems are effective in day time more than in night time. Due to high contact surface between sprayed water and condenser, the power consumption could be saved by around 23%, and can increase COP up to 42%. Apply spray water cooling system is more effective specially in the hot weather countries. This is also will led to increase the duration life of the cooling unit.

As the conditioned space temperature decreased the cycle COP increased due to the temperature decreased and so cold moist air for condenser cooling, As the outside environmental temperature decreased the cycle COP increased due to low condensing temperature observed. Spraying room temperature water onto the condenser cooling air increases the performance of the refrigeration cycle specially if this water at low temperature as possible.

By Applying spray water, the pressure in the condenser reduced 28.2%, While the pressure in the evaporator reduced about 9%, and pressure ratio across the cycle reduced about 18.8 %. With respect to the condenser temperature in the cycle, it is reduced 17.4%, while the evaporator temperature reduced 5.1%, this is another indication of reduction in pressure ratio of cycle.

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