# STUDY TO ENHANCE THE PERFORMANCE OF AIR COOLING SYSTEM BY MIXING DIRECT EXPANSION UNIT AND CHILLED WATER SYSTEM

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Abstract :

The proposed system consists of two air conditioning sub systems. The first is a water cooling heat exchanger system which works as an air pre-cooler for the conventional mechanical vapor compression refrigeration system (VCR). The proposed system is using (R-22) as a refrigerant which is investigated for warm and hot climates. The results indicate that by using indirect heat exchanger system can reduce cooling load from 6% to 40% during cooling season and also from 10 % to 16 % reduction in electrical energy consumption for the used unit 2.02 hp along the test rig running. Moreover the heat recovery system and its open cooling water cycle on the water cooled condenser save a hot water temperatures ranged from (30 $^{o}$C – 35 $^{o}$C) available for using continuously as the VCR system running. From the other side, the water cooled condenser removes back pressure on the compressor better than air cooled condenser, which will increase compressor operation life. Improve the performance of the refrigeration unit by combined a pre- cooling system to remove a part from the sensible in the outdoor air and this will occur by studying the work experimental and theoretical. Its experimental relevance studies the performance of the new system through calculating the cooling capacities of the new system. The theoretical expectation of the performance of the new system by changing parameters the same in experimental plus other parameters done in theoretical model only such as water heat exchanger cooling water temperature and flow rate, and water heat exchanger effectiveness.

***Keywords:*** *Modified VCR cycle, Energy recovery, Pre-cooling system, Water cooled condenser.*

## 1. Introduction

In commercial and residential buildings air-conditioning systems are mainly for the occupant’s health and comfort. They are often called comfort air-conditioning systems. Because of the size of the new system, it may be available for a wide variety applications such as; Large buildings (hotels, hospitals, factories, restaurant, governmental offices.etc), and Large ships.

The previous studies have demonstrated the dependence of the possibility of improving the refrigeration systems to achieve comfort, heat recovery, and energy savings. Heidarinejad G. et al. [1] studies the possibility of using indirect evaporative cooling [IDEC] systems by utilizing in a recovery cycles (secondary flow from indoor air) to achieve lower temperatures. Also, water heat exchanger systems can be used as a pre-cooling unit before mechanical cooling systems in climates with high temperatures as in the proposed system. Advantages from using water heat exchanger as a pre-cooling unit before mechanical cooling systems, the energy consumed by water heat exchanger stage is much less than the energy saved from reducing the load on a refrigeration system as a result, the overall energy consumption of the system will reduces. Another saving could result from the reduction in size of refrigeration equipment required. The water heat exchanger system may also reduce the total operational time of refrigeration equipment during the year [1].

In the past two decades, extensive studies of evaporative cooling systems that include direct and indirect evaporative cooling equipment have been conducted. The main objective of these researches was to determine the energy saving potential of the evaporative cooling technology applied to residential and office buildings. The need to reduce peak power as well as save energy requires new approaches to the design and research of evaporative cooling systems. Some dry-surface installations have second stages of refrigeration or direct evaporative cooling [3].

Liddament M. W., and Orme M. [2] explain the breakdown of typical total building electrical energy consumptions are the largest energy consumer and thus potentially an area where large energy savings may be realized [2]. Mainly Energy Efficiency Savings Opportunities are Optimize heat exchange process by Proper sizing of heat transfer areas in process heat exchangers and evaporators. Also, optimizing the driving force i.e. the difference between evaporator temperature Te and condenser temperature Tc . Noting, a 1 $^{o}$C raise in evaporator temperature can save almost 3 % of the power consumed. To study the effect of evaporation temperature on the compressor power consumption table (1) shows that at constant condenser temperature Tc of 40 oC, low evaporator temperatures reduce the refrigeration capacity TR and increase the power consumption. An example for a reciprocating compressor using R-22 refrigerant evaporator temperature 10 $^{o}$C will show these effects in table (1) and table (2).

Table (1) Effect of Evaporation Temperature on the Compressor Power Consumption:

| **Evaporator Temperature ($^{o}$C)** | **Refrigeration Capacity (tons)** | **Specific Power Consumption (kW/TR)** | **Increasing (%)** |
|---|---|---|---|
| 5.0 | 67.58 | 0.81 | — |
| 0.0 | 56.07 | 0.94 | 16.0 |
| -5.0 | 45.98 | 1.08 | 33.0 |
| -10.0 | 37.20 | 1.25 | 54.0 |
| -20.0 | 23.12 | 1.67 | 106.0 |

The next table (2) shows the effect of condenser temperature on the compressor power consumption. At a constant evaporator temperature Te of 10 $^{o}$C, increasing the condensing temperature leads to a reduction in refrigeration capacity and an increase in power consumption.

Table (2) Effect of Condensing Temperature on the Compressor Power Consumption:

| **Condensing Temperature ($^{o}$C)** | **Refrigeration Capacity (tons)** | **Specific Power Consumption (kW /TR)** | **Increasing (%)** |
|---|---|---|---|
| 26.7 | 31.5 | 1.17 | — |
| 35.0 | 21.4 | 1.27 | 8.5 |
| 40.0 | 20.0 | 1.41 | 20.5 |

So it's important to keep the difference between Te and Tc at an optimum level to ensure the best TR at the lowest power consumption for running the system.

Air cooled with water spray, and shell and tube condensers with water-cooling Selection; Operating at low discharge pressure values and improves the TR capacity of the refrigeration unit and thus reduces the power consumption. For example, if the refrigerant R-22 is used in a water-cooled shell and tube condenser then the discharge pressure is 14 kg/cm$^2$. On the other side if the same refrigerant is used in an air-cooled condenser then the discharge pressure is 20 kg/cm2. This shows how much additional compression duty is required, which results in almost 30% additional energy consumption by the plant.

Watt J. and Brown W. [4], study in rare humid weather, when the regenerative dry surface was inadequate, the refrigeration stage supplemented it. The evaporative coil followed the main cooling coil in air stream and performed both sensible and latent cooling. In general, the indirect stages handled the air's sensible heat, usually estimated as 70 % of total, and refrigerated coils removed mostly the 30 % of latent heat. Even quit small refrigerated stages gave satisfactory results. Gianni and olive [5], suggested the adoption of water loop heat pump system integrated with a heat recovery system for air conditioning. The results of technical and economical comparison this system with the traditional system, based on experimentation, reporting a 25% energy saving over the total air conditioning costs.

Investigation of the potential cooling techniques in arid regions of Middle East to identify comfort enhancement of evaporative cooling by means of cooling towers such systems offer savings, one cooling tower and pump can supply water simultaneously to both dry surface coils and water cooled condenser in the refrigeration system, or exhaust air from first stage cooling towers can cool second stage air cooled condensers. Condensate from refrigerated cooling coils can drain into condenser water cooled reservoir to reduce water consumption and

temperature by [6-7, and 8]. Most excess heat in outside make up or ventilating air is removed about 20 % – 30 % of the refrigeration cost.
Two stages indirect evaporator and mechanical vapor refrigeration system decreases the air's temperature sufficiently that less volume needs to circulate through the rooms than in direct evaporative cooling.
In very dry weather, on many nights or during refrigeration break down the indirect system can carry the whole load saving power and provide human comfort.
Delfani S. et al [9] have been studied the performance of using of water to a pre cool inlet air of mechanical cooling system is evaluated and results indicated that water can provide about 75% of cooling season. Also, about 55% saving in electrical energy consumption can be obtained. water is an environmentally clean and energy efficient system can be used for reducing mechanical cooling system size, peak load and electrical energy consumption during cooling season. Around 30% of fresh air is used.
The present work will try to enrich the studies in this point by experimental and theoretical relevance studies. Its experimental relevance studies the performance of the new system through calculating the cooling capacity and efficiency of the new system. Theoretical expectation to the performance of the new system by changing parameters the same in experimental plus other parameters done in theoretical model only like water heat exchanger cooling water flow rate, moisture content, and heat exchanger effectiveness.

## 2. Experimental Apparatus

The components of the new system are heat a modified mechanical vapor refrigeration unit and indirect water unit. The schematic drawing of the experimental apparatus is designed and constructed in the laboratory of Mechanical Power and Energy Department South Valley University. The system mainly comprises of compressor, condenser, double pipe heat exchanger, indirect contact heat exchanger, air simulator and water pump, as shown in figure 1.

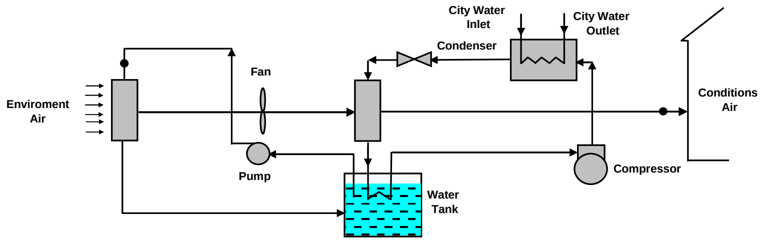


Fig. 1. Experiential Test-Rig.

### 2.1. *Description of Experimental Apparatus Components:*

**The Compressor**: The function is to circulate the refrigerant through the VCR cycle to complete the parts work.
**The water cooled Condenser:** The condenser cooling water either from the cooling tower or taken from a city water line as in experimental work. Lizardos E. J. prove that the water cooled condenser performance depends mainly on the cooling water temperature [10].
**The Modified Expansion Valve:** The Modified expansion valve is a double throttling capillary tube. The purpose of this modification to increase the compressed Freon flow spread through the modified Evaporator.
**The Evaporator:** The evaporator was modified to enhance the performance of the vapor compression system, where it was divided by area into two sections: air cooled evaporator and water cooled evaporator.
**The Water Cooling Tank:** The main function of the cooling water tank is to supply chilled water to the indirect heat exchanger.
**The Circulation Pump:** The function of the pump is to circulate cooling water from the water tank to the WATER Heat exchanger. It circulates the cooled water from the cooling tank to water heat exchanger.
**The Water Heat Exchanger:** The function of the water heat exchanger is to exchange heat between chilled water and hot air, where it's give the ability to remove a large sensible heat from the inlet air before air reach to the cooling air evaporator.
**The Air Blower:** The function is to move the outdoor air over the indirect heat exchanger and evaporator before inter the conditioned space with the required flow rate.
**The Air Simulator:** The function of the heater is to raise the air dry-bulb temperature to achieve the condition of the outdoor air before entering the water heat exchanger along the test experiments in range (30 $^{o}$C, 35 $^{o}$C, 40 $^{o}$C, and 45 $^{o}$C).

### 2.2. *Instrumentation and Measuring Devices*

The instrumentation used for recording the required measurements to analysis the performance of an improved vapor compression system. The experimental apparatus was instrumented for the measurement of; Temperature, Humidity, Air velocity, and Water velocity.

#### 2.2.1 *Temperature Measurement*

In order to evaluate the system performance, temperature measurements were carried out through the system at twelve temperature measuring point. The calibration curves results shows those thermocouple temperature sensors in a good accuracy and resolution ranged from ± 0.5 $^oC$ and 0.1 $^oC$, respectively.

#### 2.2.2 *Humidity Measuring*

The humidity measured range is 0 % to 99 % RH and the accuracy and display resolution ranged from ± 3% to 0.1% respectively. For the temperature measuring part ranges between - 40 $^oC$ and 70 $^oC$ and the accuracy and display resolution ranged from ± 0.5 $^oC$ to 0.1 $^oC$ respectively [11].

#### 2.2.3 *Air Flow Rate Measurement*

The supply airflow rate was measured by a digital Wind Meter with range between 0.2 m/s and 30 m/s the accuracy and display resolution ranged from ± 0.05 m/s and 0.1 m/s respectively.

## 3. Results and Discussions

### 3.1. *Experimental Results*

The results were obtained to study the thermal performance of the improved vapor compression system through cooling capacities. The effects of changing operating parameters such as; outdoor air temperature and its relative humidity, air flow rate, and cooling water temperature. The system results showed that the effectiveness of water heat exchanger, COP of modified vapor compression cycle and the cooling capacities.

The experimental results obtained where the inlet water temperature to the water heat exchanger varied from 20 $^oC$ to 25 $^oC$ and assumed to be constant with an average value at 22.5 $^oC$. The results show that increasing the temperature difference from 10 $^oC$ to 20 $^oC$ enhances the heat exchanger effectiveness by 11% for an air flow rate 7.7 $m^3$/min.

Moreover it can be observed that increasing the air flow rate has a bad effect on the effectiveness of the indirect heat exchanger.

#### 3.1.1 Effect of Outdoor Air Temperature

Figures 2-a, 2-b, and 2-c, shows the effect of outdoor air temperature on cooling capacity of evaporator, COP of system, and total cooling system capacity respectively. Firstly; the Rated cooling capacity of the water heat exchanger increases as the air flow rate decreases where the outdoor air temperature constant. Figure (2-a) shows that increasing the outdoor air temperature from 30 $^oC$ to 45 $^oC$ leads to increase the rated cooling capacity of the evaporator from 2.5 kW to 3 kW at air flow rate 7.7 $m^3$/min, while it was increased from2.67 kW to 3.67 kW at air flow rate 16.3 $m^3$/min and outdoor temperature 40 $^oC$. The influence of varying the outdoor air temperature on the coefficient of performance of the system for different values of air flow rate is shown in figure (2-b). It can be noticed that as the outdoor air becomes hotter the coefficient of performance of the system enhances for different values of air flow rate. The figure indicates that, at the minimum value f air flow rate (7.7 $m^3$/min), increasing the outdoor air temperature from 31 $^oC$ to 45 $^oC$ the coefficient of performance of the system increased from 2.7 to 4.2. Whereas varying of air flow rate from7.7 $m^3$/min to 16.3 $m^3$/min at a constant values of outdoor air temperature will increase the coefficient of performance of the system significantly. From figure (2-c), at inlet temperatures 11 $^oC$, 12 $^oC$, and 13 $^oC$ and air flow rate 9.4 $m^3$/min the total rated cooling capacities would be 7 kW, 5.8 kW and 4.8 kW respectively. Increasing inlet air temperature for a particular value of air flow rate will significantly decreases the cooling capacity of the vapor compression system.

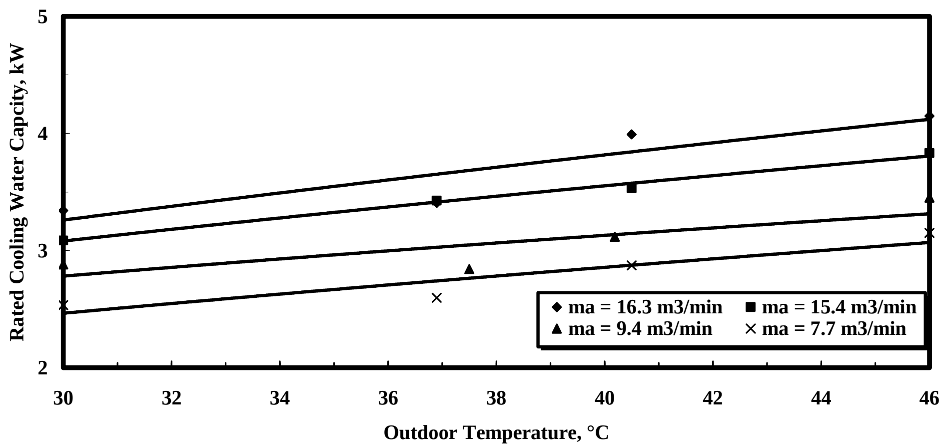


Figure (2-a) The Effect of Outdoor Air Temperature on the Rated Cooling Capacity of Evaporator.

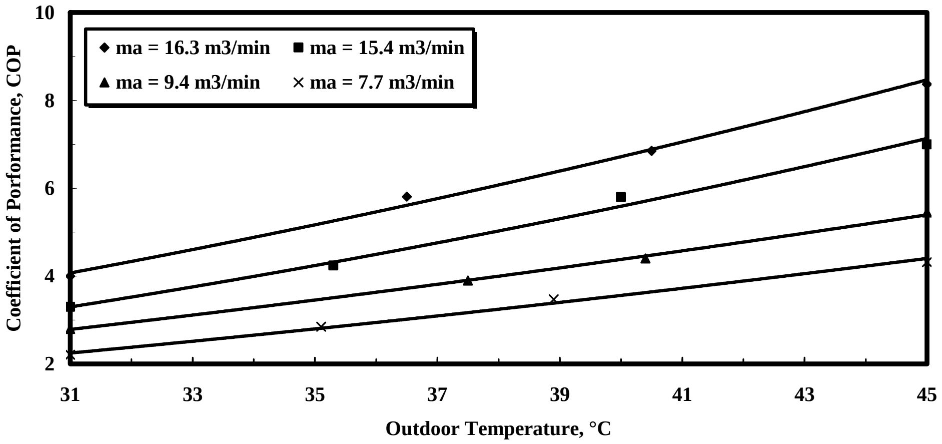


Figure (2-b) The Effect of Outdoor Air Temperature on the Coefficient of Performance of the System.

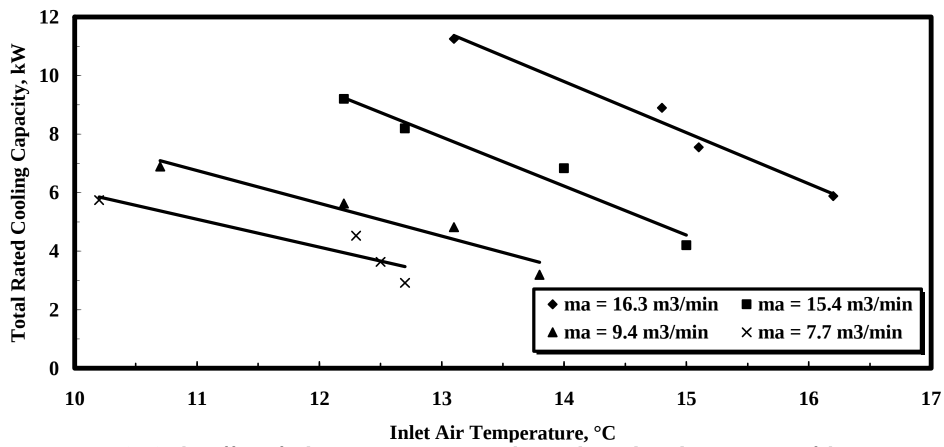


Figure (2-c) The Effect of Inlet Air Temperature on the Total Rated Cooling Capacity of the System.

### 3.2. *Theoretical Testing Results*

A theoretical model is developed to predict the performance characteristics of the proposed system for a wide range of operating conditions over the tested in the Rated experimental test facilities. The effect of variable air flow rate and outdoor inlet temperature (30 $^{o}$C, 35 $^{o}$C, 40 $^{o}$C, 45 $^{o}$C) the same in experimental testing conditions. It is desired to predict the total proposed system cooling capacities, Rated VCR and water heat exchanger cooling capacities. The theoretical model took only sensible cooling into account. More condensation developed in case of low air flow rates producing low air temperatures. At high specific humilities and lower air flow rates the latent load will become appreciable and the theoretical model will not be accurate. From the specific

humidity and the conditioned space temperature stayed constant at 25 oC. With air flow rate, Outdoor temperature, and water cooling inlet temperature, the heat exchanger effectiveness could be calculated by number of transfer unit NTU.
As Rated water heat exchanger and cooling water cooling capacities is calculated from;

$$Q_{aHx} = M_a C_{pa} (T_o - T_{ae1}) . \qquad (1)$$

$$Q_w = M_w C_{paw} (T_{wo} - T_{wi}) . \qquad (2)$$

Then the air and water exit temperature could then be calculated from;

$$T_{ae1} = T_o - (\varepsilon Q_{max} / C_a) . \qquad (3)$$

$$T_{we} = T_{wi} + (\varepsilon Q_{max} / C_a) . \qquad (4)$$

Using inlet air - to- evaporator temperature (equal to exit air temperature Tae1) and mass air flow rate, the refrigeration unit cooling capacity is calculated the heat exchanger effectiveness could be calculated by number of transfer unit NTU.

$$Q_{a\ VCR} = Q_{fHx} = \varepsilon Q_{max} . \qquad (5)$$

3.3. ***Comparison between Experimental and Theoretical Results:***

This comparison discusses the variation between experimental and theoretical results in case of changing the air flow rate (7.7 $m^3$/min, 9.4 $m^3$/min, 15.4 $m^3$/min, and 16.3 $m^3$/min), cooling water flow rate 0.18 $m^3$/min, outdoor air temperature varied between (30 $^oC$, 35 $^oC$, 40 $^oC$, and 45 $^oC$ ) and the cooling water temperature was 22 $^oC$. Figure (3) show experimental and theoretical results for air flow de calculations have the same slope trend and nearby curves.

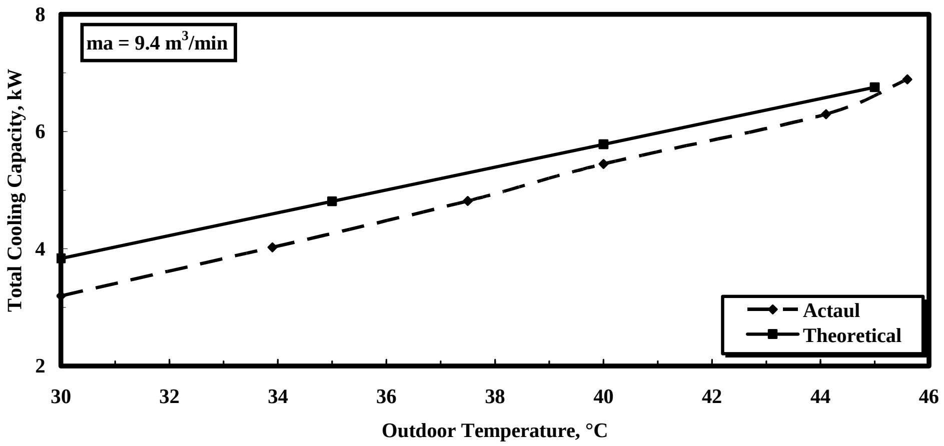


Figure (3) The Total System Cooling Capacity at Air Flow Rate 9.4 $m^3$/min.

3.4 ***Simulating of System Performance:***

To simulate the system performance over day, a residential home in Qena district with a design cooling load of 2.5 tons was used. To obtain an effective overall heat transfer area coefficient (UA) the design load was divided by difference between the design temperatures for Qena district 45 $^oC$ and the required indoor design temperature 18 $^oC$. The effective UA was calculated to be approximately (325.37 W-h/ $^oC$). Outdoor temperature was calculated every hour as a function of the time of the day.

From the effective heat transfer coefficient and outdoor temperature as a function of time of day the cooling load was calculated from equation (6);

$$Q_{tcl} = UA(T_o - 18). \qquad (6)$$

The simulations were run for an entire day for temperatures higher than 32 $^{o}$C and turn the air conditioning system off for temperatures below 32 $^{o}$C. The air conditioning systems applied are VCR, water heat exchanger, and the new proposed system and shows the relative cooling capacities for each system is calculated. The results of these cooling capacities are shown in figure (4) and figure (5) as a function of the day hours. There is only cooling loads for thirteen hours and the rest of the day hours the weather was good and systems were off to save electric power.

In figure (6) the cooling capacities for several refrigeration systems of the same operating conditions are shown. For the indirect evaporative cooler the cooling capacity was low as the heat exchanger effectiveness is low for higher air flow rates. The cooling capacity of the refrigeration VCR unit was very good and satisfactory to remove the required cooling load, but as expected with high electrical power consumption is shown in theoretical model. Also for power saving analysis figure (9) shows the energy consumed during the running hours of the conventional VCR and the new proposed system. While the suitable new system operating conditions to removing the required cooling load over the entire day hours with specific humidity equals 0.014 kgw / kga , cooling water temperature equals 20 $^{o}$C, heat exchanger effectiveness equals 0.7 as flow rate decreased and entire day outdoor temperatures shown in figure (10) and the suitable flow rate equal 300 m$^3$/HR shown below which offer more advantages from low air draft, less electrical power consumption.

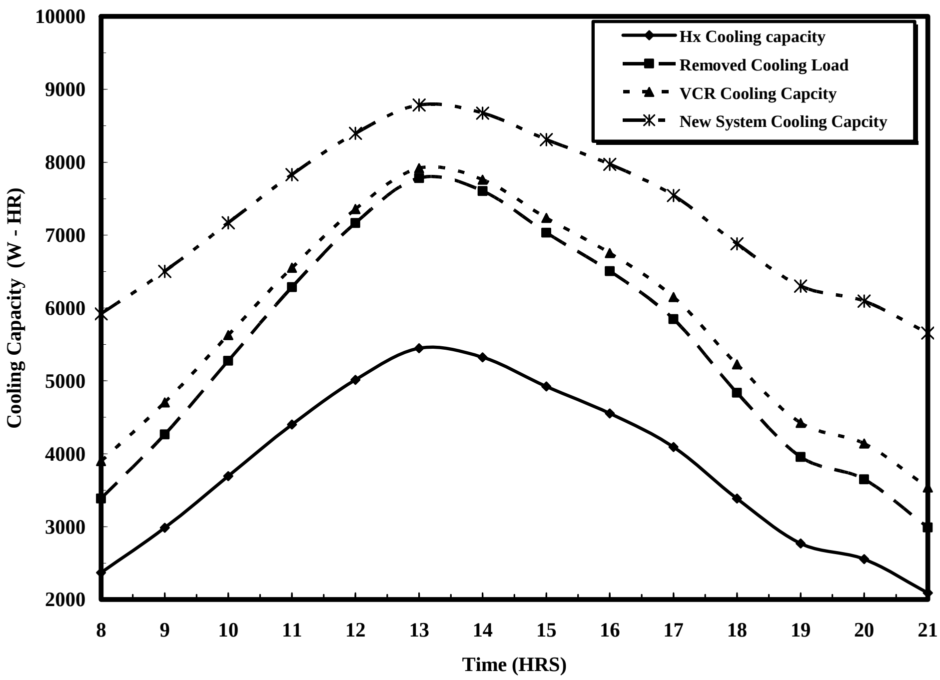


Figure (4) The Cooling Capacity Variations in Each System for a Day Operation.

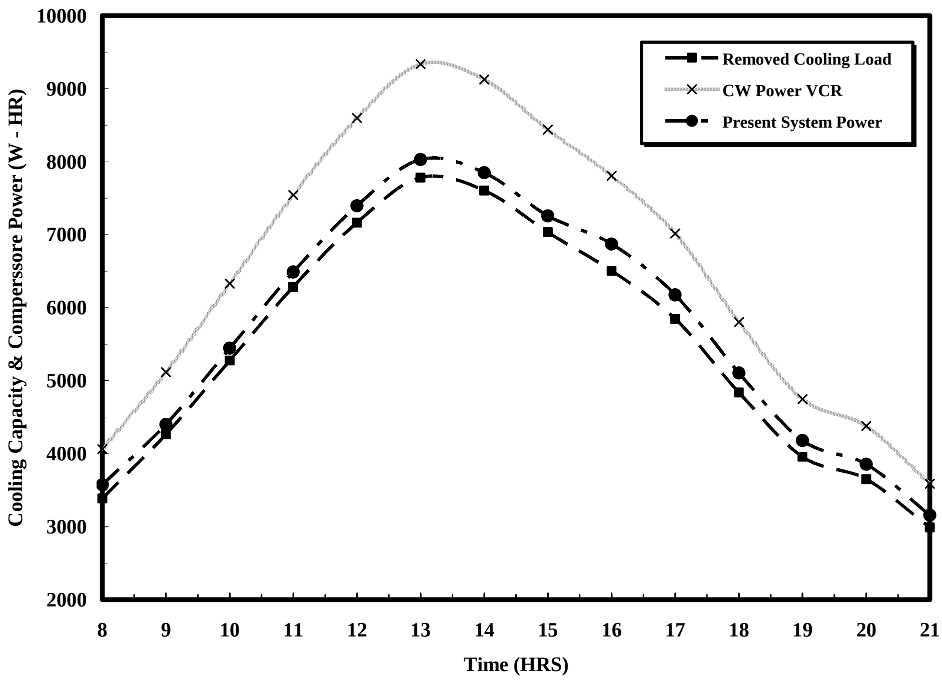


Figure (5) The Power Consumption in the VCR and the New System.

The new system offers a good performance, because the water heat exchanger removes a portion of the cooling load and air temperature at inlet to the VCR unit become low less than 30 $^{o}$C. This reduces the compressor power consumption per unit cooling capacity. At the same time the power consumed in the water heat exchanger approximately increased with increasing cooling load but was less than the power saving from VCR unit with high water specific heat (CPw= 4.186 kJ/k g.K & CPf= 1.26 kJ/ kg.K) and save much power as shown in figure (6). So, the total system cooling capacities increased as indirect heat exchanger effectiveness increased up to reach and save electrical power and more comfort with totally fresh air.

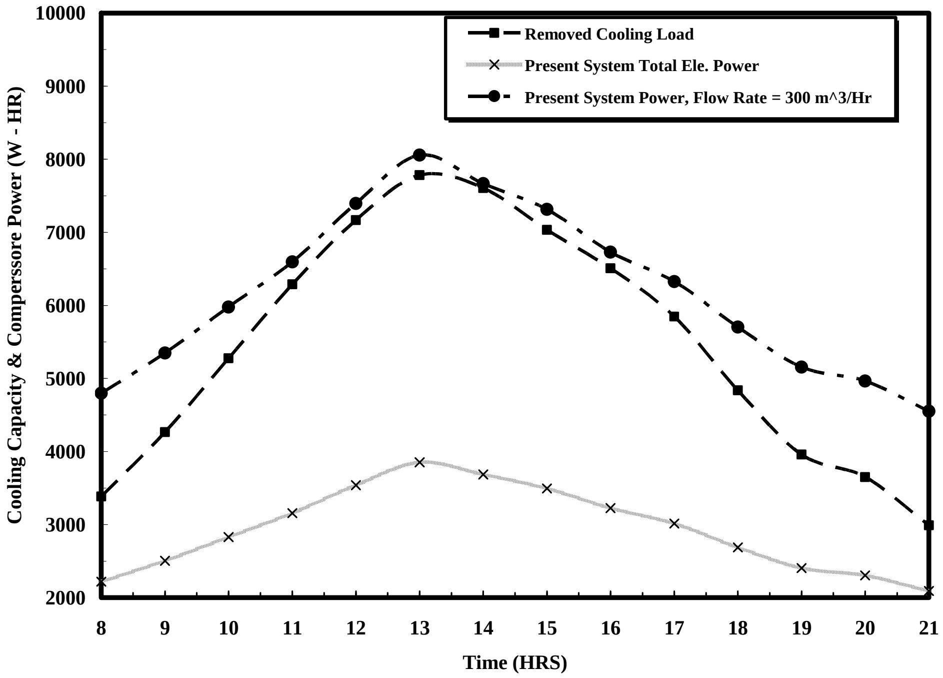


Figure (6) The New System Cooling Capacity and Compressor Power One Day Operation.

## 4. Conclusion

The conclusions could be drawn as follows:

- The lower air cooling temperature and reduced air flow requirement of this system as compared to evaporative cooling systems to meet the same cooling load.
- Moderate air temperature exit from the VCR evaporator to eliminate the possibility of compressor over loading and left partial cooling load for direct contact evaporator in the closed water cycle cooling tank.
- High air flow rates across the condenser and evaporator than conventional VCR units result in greater.
- More comfortable living environment due to total fresh air charge.

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