

Mechanical and Energy Engineering

**Two Stage Evaporative Cooling of Residential Building
Using Geothermal Energy**

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ABSTRACT

The weather of Iraq has longer summer season compared with other countries. The ambient temperature during this season reaches over 50 °C which makes the evaporative cooling system suitable for this climate. In present work, the two-stage evaporative cooling system is studied. The first stage is indirect evaporative cooling (IEC) represented by two heat exchangers with the groundwater flow rate (5 L/min). The second stage is direct evaporative cooling (DEC) which represents three pads with groundwater flow rates of (4.5 L/min). The experimental work was conducted in July, August, September, and October in Baghdad. Results showed that overall evaporative efficiency of the system (two coils with three pads each pad of 3cm) reach to 167 % with the temperature difference between ambient and supply is 26.2°C. While it reached 122.7% (one coil with three pads) with the temperature difference between ambient and supply is 16°C and reduced to 84.88% and 84.36% for IEC and DEC respectively.

Keywords: Evaporative cooling, indirect-direct evaporative cooling, geothermal energy.

التبريد التبخيري ذو المرحلتين لمبنى سكني باستخدام طاقة باطن الارض

الخلاصة

يمتاز فصل الصيف في العراق بانه من اطول فصول السنة مقارنة مع البلدان الاخرى. حيث تصل درجة حرارة المحيط الخارجي الى اكثر من 50 درجة مئوية مما يجعل نظام التبريد التبخيري مناسب لمثل هذه المناخات. يتكون الجزء العملي من نظام التبريد التبخيري من مرحلتين. المرحلة الاولى تتكون من التبريد التبخيري الغير مباشر المتمثل بالمبادلات الحرارية وبمعدل تدفق مياه جوفية 5 لتر/دقيقة. أما المرحلة الثانية فانها تتألف من التبريد التبخيري المباشر المتمثل بحشوات كارتونية ذات سمك 3 سم مع معدل تدفق مياه جوفية (4.5) لتر/دقيقة. اجريت التجارب العملية في بغداد خلال شهر تموز و اب و ايلول وتشرين الاول. أظهرت النتائج ان كفاءة التبريد التبخيري لمرحلتين مبادلان حراريان مع ثلاثة حشوات (سمك كل حشوة 3سم) تصل الى 167% مع فرق درجات حرارة الهواء الخارجي والمجهز تصل الى 26.2 درجة سليزية. بينما تصل الى 122.7% باستخدام (مبادل حراري واحد مع ثلاثة حشوات) مع فرق درجات حرارة الهواء الخارجي والمجهز تصل الى 16 درجة سليزية وتخفض الى 84.88% و 84.36% للتبريد التبخيري الغير مباشر والمباشر على التوالي.

الكلمات الرئيسية: التبريد التبخير، التبريد التبخيري الغير المباشر، طاقة باطن الارض

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1. INTRODUCTION

In recent times, the trend towards the use of renewable energies has become very important for reducing the consumption of energy in general and fuel in particular. Geothermal energy has been used in the process of cooling or heating the space by using a heat exchanger. The weather of Iraq has a long summer season compared with other countries. This season has the high air temperature and low relative humidity. Reducing air temperature inside space is one of the major problems. Air-conditioning systems are used in many residential and industrial fields to provide comfortable environmental conditions for living and working. It was not limited to humans but can provide a suitable environment for the animals and plants contribute to increased production. But still, the air-conditioning systems consumed a large amount of energy.

Evaporative cooling is ambient friendly energy and an efficient cooling way which only uses water for cooling air through the simple evaporation of water. The evaporative cooling systems work better in hot, dry climates and it can also be used in more humid climates. Evaporative cooling has three types which are direct evaporative cooling (DEC), indirect evaporative cooling (IEC) and indirect/direct evaporative cooling (IDEC).

The geothermal energy (also known as ground source) is one of the important renewable energy that reduces the consumption of energy and it is an ambient friend, a practical option available to Iraqi's farms. Besides; the groundwater may be used as an irrigation water source. The geothermal energy is used for air-conditioning and space heating of the domestic and commercial building, **Heidarinejad, 2009**. The method of using geothermal energy depends on the geothermal temperature which is proportional to the depth (which also depends on the geothermal media and location).

El-Dessouky, et al., 2004, built an experimental rig of a two-stage evaporative cooling unit. The efficiency of the DEC was strongly dependent on the pad thickness and water flow rate. It varied over a range of (63-93) % as compared to stand DEC unit alone which is between (50-75) %. This is attributed to the cooling effect of the IEC unit. **Heidarinejad, et al., 2009**, studied experimentally the performance of the indirect-direct evaporative cooling system in multi-climate conditions. The experimental result was that the effectiveness of indirect change is between (55%-61%) and the overall effectiveness various between (108%-111%) and the power consumption for the indirect-direct evaporative cooling system is less than mechanical system (VCRS) by 60%. The parameters that affect the performance of evaporative cooling was studied by, **Kareem, and Imad, 2009**, like ambient temperature (dry bulb temperature (DBT) and wet bulb temperature (WBT)) and water flow rate. The experimental results were that the maximum water flow rate that must be used in the system was about (450L/h) and DBT&WBT for air were (42°C & 21.9°C) respectively. The results were obtained from the above parameters: the efficiency of cooling was 61.48%, the coefficient of performance was 33.5 and specific power consumption of 4.7 W.min/kg dry air. **Kulkarni, et al., 2011**, examined the performance of the indirect-direct evaporative cooling system (IDEC) by many shapes of the pad and cooling media in a direct evaporative cooling (DEC) while they represent the indirect evaporative cooling (IEC) by plate heat exchanger. The experimental results were: the efficiency of direct evaporative cooling varied between 71.9% to 98.3%, cooling capacity change between 3240 kJ/h to 4542 kJ/h, the total efficiency was varied between 74.3% to 119.5% and total cooling capacity varied between 4679 kJ/h to 4377 kJ/h. The air temperature at outlet changed between 27.3°C -32.4°C using IDEC system and they got the maximum power consumption of 203 W and 418 W for DEC and IDCE respectively. **Jain, et al., 2011**, experimentally studied the effectiveness of the different types of fibers used in an evaporative cooling system in India. They used four types of fibers in their test which was (aspen fiber, khus fiber, coconut fiber and Palash fiber). The result

of the experimental work was: the effectiveness of Palash fiber was about 13.2% and 26.31% greater than of aspen and khus fiber respectively. While the effectiveness of coconut fiber was about 8.15% greater than of khus fiber and similar to that in aspen fiber. Also, in the experimental work, they got the maximum pressured drop when they used aspen fiber and minimum pressure drop when they used khus fibers.

In the present study, the two-stage evaporative cooling system was designed and constructed from available materials in the Iraqi market. The geothermal was water used as a cooling fluid for the indirect-direct evaporative cooling system (IDEC). Also, the effect of changing the design parameters of IDEC such as the number of the heat exchanger, number of pads, performance was investigated in the present work.

2. EXPERIMENTAL WORK

The experimental domestic room was constructed on a building in Baghdad. This location enabled close follow up and long day monitoring of all design and performance parameters and the provision of continuous water and electricity to the installation.

2.1 Experimental Facilities

The test rig consists of four main parts which are the domestic room, geothermal water well, indirect /direct evaporating cooling system, and measuring instruments.

2.1.1 Domestic Room Design

The room is designed, constructed, and located in Baghdad (latitude 33.3°N, longitude 44.4°E, and altitude 32 m above the sea level). The shape used in the presented room is a fixed building. The geometric distinctiveness of the room shape model are as follows: height (H) 2.85m, the length (L) 4 m and width (W) 3.4 m. The room was built from bricks of 24 cm thickness with cement of 4 cm with gypsum of 3cm and plaster 1cm. The cooling unit is located on the south-east side and the door on the south-west side. **Fig.1** shows the schematic diagram of the designed room and IDEC unit.

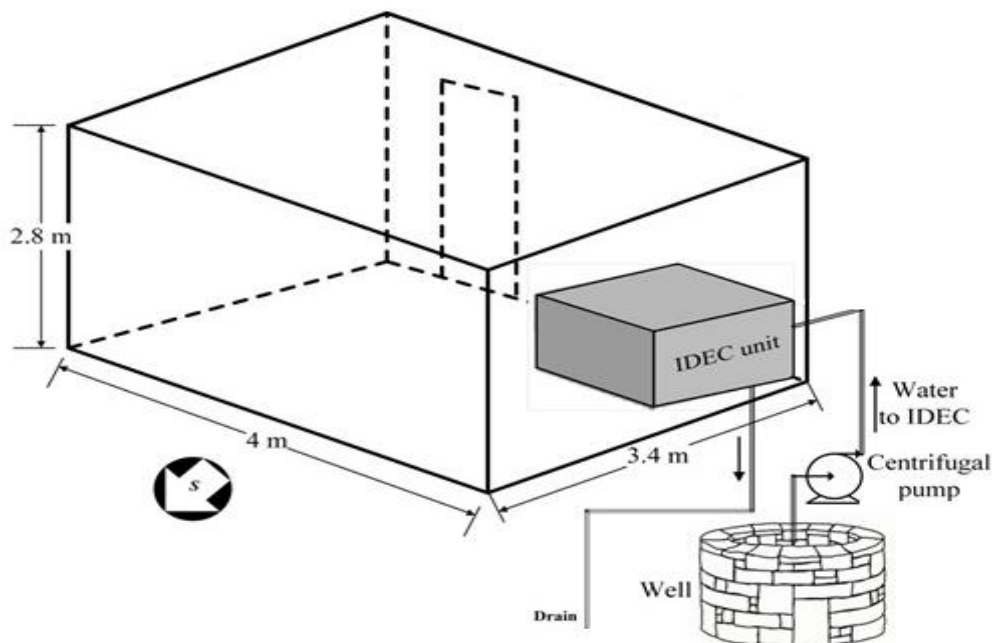


Figure 1. The Schematic Diagram of the Designed Room.

2.1.2 Indirect-Direct Evaporating Cooling Unit

The required flow rate can be evaluated depending on the room dimensions and structure using Eq.(1), **Khalid, 1986**.

$$\dot{V}_s = \frac{RSL}{1.22(T_r - T_s)} \tag{1}$$

Where:

- \dot{V} : is the air flow rate required (m³/s)
- RSL: Room Sensible Load (Watt)
- T_r: Room Temperature (°C)
- T_s: Supply Temperature (°C)

The supplied centrifugal fan operated by 330 Watt, 230V,1.5A, and 2200 RPM AC motor, constant speed with $\dot{V} = 0.345$ m³/s, provided the power needed to overcome the pressure losses over the coils and pads sections. The temperature difference in Eq. (1) is 4.5°C. Schematic diagram of the indirect-direct evaporative cooler is shown in the **Fig. 2**

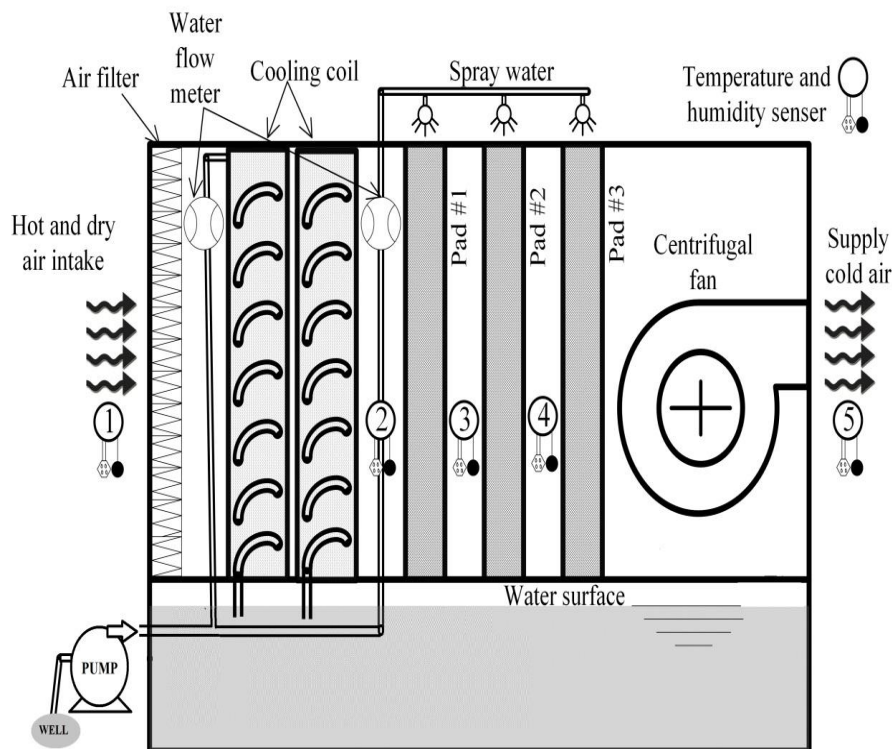


Figure 2. Schematic Diagram of Cooler Indirect- Direct Evaporating Cooler.

The cooling coil for the indirect stage of the evaporative cooling system consists of two heat exchangers (depending on the case study) in the entrance of the system so that the ambient air was entered first to the heat exchangers. The first heat exchanger located by 10 cm before the second heat exchanger and the second one located by 5.5 cm in front of the first pad stage for a direct evaporative cooling (DEC). The DEC stages consist of three pads or two pads or one pad with 3cm thickness (depending on the case study) made from cellulose and the distance between each two is 5.5cm. The heat exchangers are made of 39 tubes of copper attached with straight fins (the tube is 6 mm diameter and 0.4 mm thickness). The pipes locations in the rig are

horizontal. The heat exchangers dimensions are 0.33 m high, 0.365 m wide and 0.065 m thick for each one. The system duct area is $(0.38 \times 0.44) \text{ m}^2$ that is made of galvanized steel plate with the structure of steel, dimensions of pads is $(0.33 \times 0.4) \text{ m}^2$ each. The velocity of the air through the pad, for this dimension, is about 2 m/s and this gives overall evaporating pad efficiency of about 70 %, **Lawrence, 2005**. The schematic diagram is shown in **Fig. 2** and a picture of the cooler is shown in **Fig.3**.

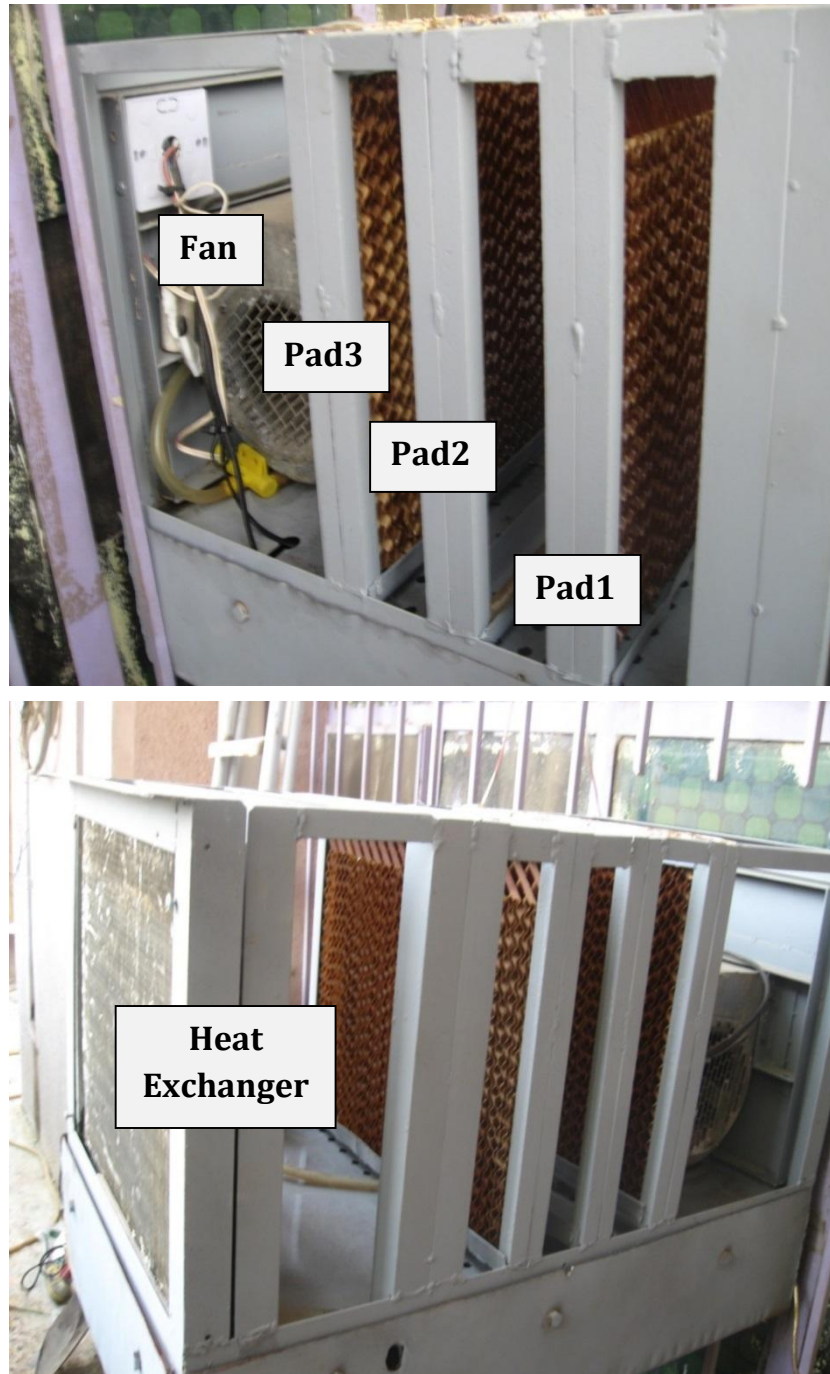


Figure 3. Experimental Setups of the Indirect-Direct Evaporating Cooler.

2.1.3 Centrifugal Pump

A centrifugal pump is driven by a (0.5 HP) with a maximum head of 40 m, made in Italy. The pump is fixed near the well which is used to pump the well water to the coils and pads. The pump was tested and calibrated by reducing energy equation to the form in Eq.(2) to find the operating point and it was closely found at head pump about 23 m and flow rate about 21 L/min, as in **Fig.4**.

$$H_p = (Z_2 - Z_1) + \frac{8Q^2}{g\pi d^4} X(1 + f \frac{L}{d}) \tag{2}$$

$$f = 0.316Re^{-0.25} \tag{3}$$

$$Re = \frac{4m}{\pi d^2 \mu} \tag{4}$$

Where:

H_p : pump head (m)

Z_2-Z_1 :8.5m

Q : water flow rate (m^3/s)

d : pipe diameter (1.25 cm)

L : pipe length (17 m)

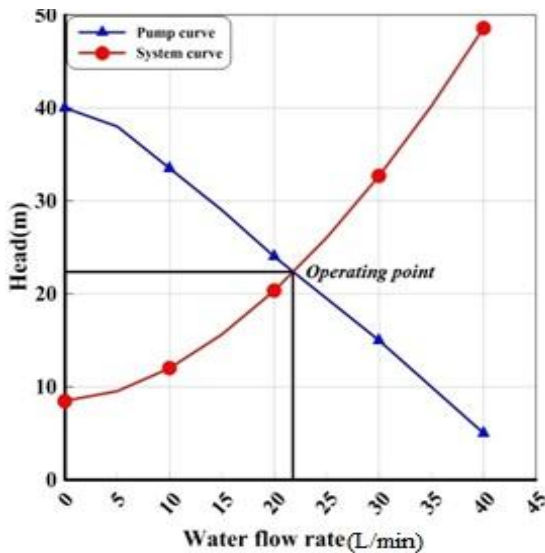


Figure 4.The Centrifugal Pump used and the Relation Between the Head and the Water Flow.

2.1.4 Geothermal Water Well

The well is used to make geothermal water for cooling as well as another use. The temperature of the well water is changing from (25.25-25.69) °C in the summer season. In the present well, the borehole is 150 mm and the PVC well casing is 110 mm with 6 mm thickness is used. the



casing pipes are slotted with narrow slots to ensure that the groundwater flows through them without soil particles or stones. The theoretical research point that this slot size or width is lower than the size of small particles in the soil. The slot size used in the present well is (1mm) which was made by hand using a hacksaw as shown in **Fig.5**.The depth of the well is 8 meters.



Figure 5. Cutting Slots of PVC Pipes Used In The Well.

The suction pipe well is 25 mm in diameter with 1” PVC FOOT check VALVE was installed in the bottom submersible end of the pipe. As shown in **Fig.6** the upper end of the suction pipe was connected to the pump. The upper face of the well was protected against stones and clays using base cut water bottle 20L. The geothermal well which is used as the makeup water has the depth of 8m; **Fig.7** shows the built well.



Figure 6. Pvc Foot Check Valve.



Figure 7. The Built Present Well.

2.2 Testing procedure

The test began usually around 9:00 AM to 4:00 PM, run for about 7 hours, according to the following procedure.

1. Preparing the cooler for the certain conditions such as a number of coils and number of pads used in the test.



2. The cooler is run for 15 minutes which is the time required for reaching a steady state condition. Through this period, the input test parameters were measured such as water flow rates, air flow rate, air pressure drops through the different processes.
3. The measurement systems are run such as water temperature measurement, humidity and temperature measurement for ambient, processes and inside the room. The period between two reading is 30 minutes.
4. The number of the pad is changed from one pad to three pads (pad thickness 3cm)
5. The steps are repeated from 1 to 5 with new numbers of the pad
6. The number of the heat exchanger is changed from one to two and the steps above are repeated.
7. After recording the inlet and outlet temperature for each section with wet bulb temperature for the inlet section using the psychrometric chart, the evaporative efficiency is found using the equation below

$$\eta = \frac{T_{in} - T_o}{T_{in} - T_w} \tag{5}$$

8. LMTD is computed from the recorded temperatures for the heat exchanger inlets and outlets using the equation below and it is necessary to compute the capacity of heat exchangers from Eq.(6). The maximum value for LMTD is representing the best condition for the working heat exchanger.

$$q_{IEC} = U \times A \times LMTD \tag{6}$$

$$LMTD = \frac{T_1 - T_2}{\ln \left[\frac{R}{R + \ln(1 - RP)} \right]} \tag{7}$$

Where R and P are given by

$$R = \frac{t_{w2} - t_{w1}}{T_1 - T_2} \tag{8}$$

$$P = \frac{T_1 - T_2}{T_1 - t_{w1}} \tag{9}$$

The overall heat transfer coefficient U is:

$$U = \left(\frac{1}{h_w} \frac{A_o}{A_i} + R_{fw} \frac{A_o}{A_i} \frac{A_o b}{A_i k_t} + R_{fa} \frac{1}{h_a} \right) \tag{10}$$

Where;

h_a : The air side heat transfer coefficient (W/m² K)

h_w : The water side heat transfer coefficient (W/m² K)

R_{fa} : Outside fouling resistance $R_{fa} = 0.00009 \text{ m}^2\text{K/W}$

R_{fw} : Inside fouling resistance $R_{fw} = 0.35 \text{ m}^2\text{K/W}$

A_o : Outside heat transfer area of IEC heat exchanger (m²)

A_i : Inside heat transfer area of IEC heat exchanger (m²)



k_t : Conduction heat transfer coefficient of copper tube (401 W/mK)

And b : tube wall thickness (0.0006 m)

Where v : air velocity (m/s)

3. RESULTS AND DISCUSSIONS

3.1 Performance of Indirect-Direct Evaporative Cooler

The cooling system which is designed for two air-water heat exchangers as an indirect evaporative cooler (IEC) and three pads with 3cm pad thickness as the direct evaporative cooler (DEC). The temperature after each component is plot against the time as shown in **Fig.8**. The maximum ambient temperature reaches to 51.8°C at 12:30 pm and the temperature difference between maximum ambient temperature with temperature after (coil#1,coil#2, pad#1, pad#2, pad#3) and with supplied air temperature are 16.2°C, 22°C, 24.5°C, 26.1°C, 27.6°C, and 25.9°C receptivity.

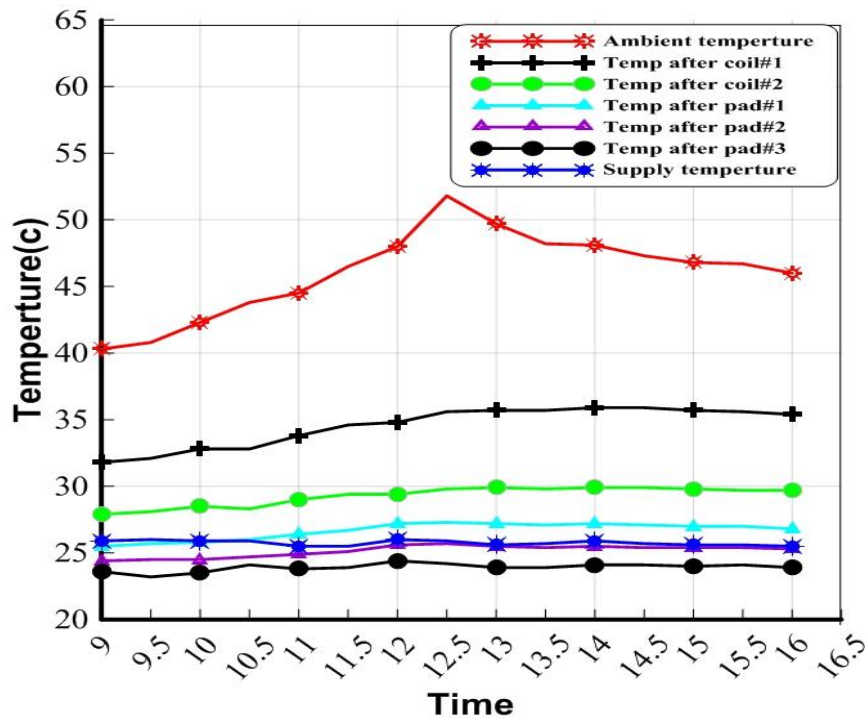


Figure 8. Relation Between Temperature vs Time (10/8/2017).

The relative humidity increased with the decreasing temperature for all cases as shown in the **Fig.9**. The relative humidity after each component was shown. At the maximum ambient temperature (51.8°C) the relative humidity was 6.1% and then it's beginning to increase after coil #1, coil #2, pad #1, pad #2 and pad #3 to 21.4%, 27%, 49.9%, 65.6% and 75% and then decreased to 68.5% at exit fan because the air is heated by electrical motor fan finally RH for the conditioned space reached 53.2% because that the airflow is heated by the load in the room.

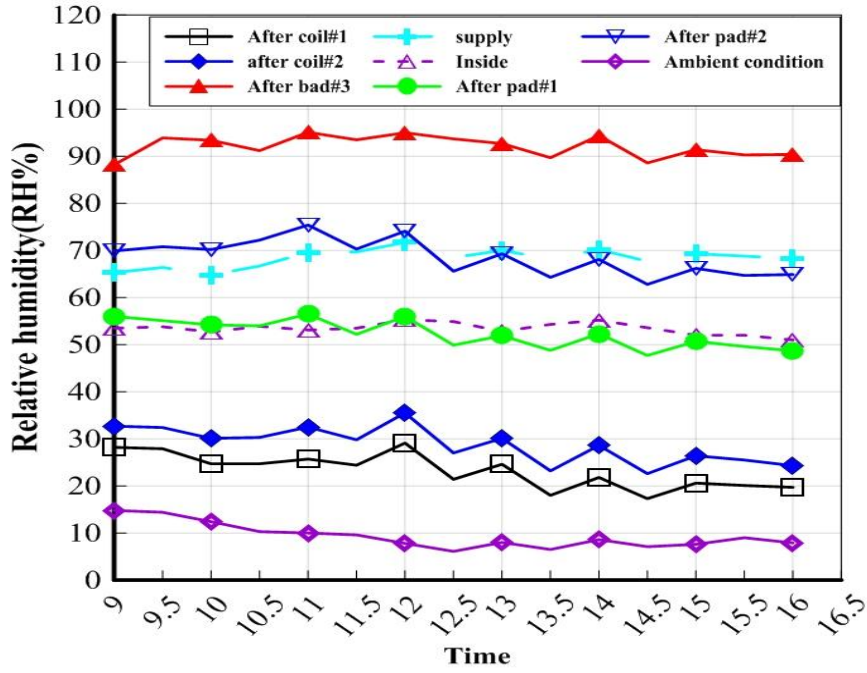


Figure 9. Relation Between RH After Each Component vs Time (10/8/2017).

The performance parameter for any evaporating cooling system is the evaporative efficiency, which was defined by the ratio of dry bulb temperature difference to the difference between the input dry bulb temperature and wet bulb temperature. The use of the psychrometric chart is to evaluate the wet bulb temperature. The wet bulb temperature for the air inlet T_{w1} and outlet T_{w2} of the first heat exchanger and outlet T_{w3} of the second heat exchanger were plotted with time as shown in Fig.10.

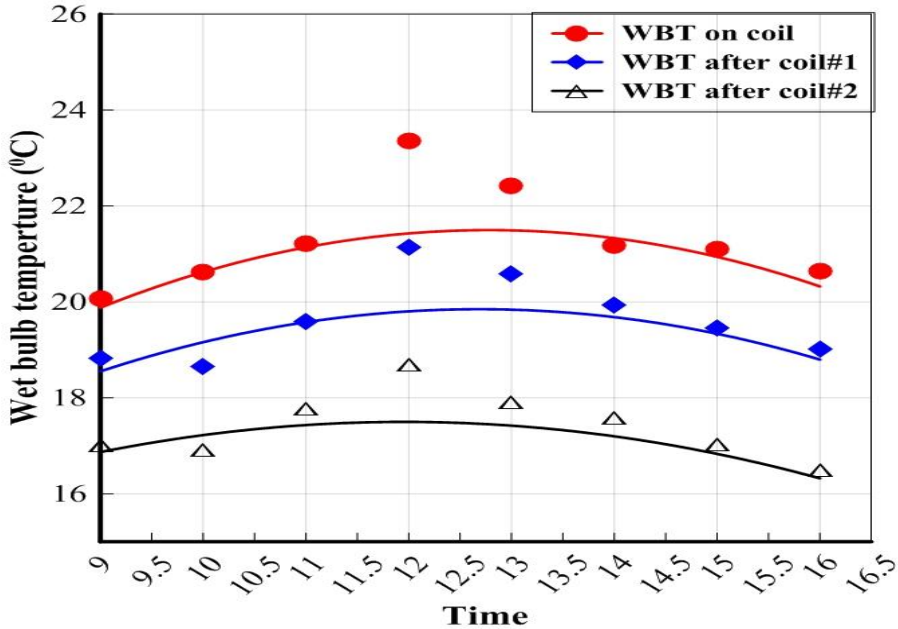


Figure 10. Relation Between Wet Bulb Temp Vs Time (10/8/2017).

To estimate the evaporative efficiencies for the different pads (η_{DEC1} , η_{DEC2} and η_{DEC3}) and the overall evaporative efficiency of the direct evaporative stage η_{DEC} and the evaporative efficiency

of the first and second heat exchangers η_{IEC1} & η_{IEC2} . The evaporative efficiency for all system was calculated using Eq.(11)

$$\eta_{IDEC} = \frac{T_1 - T_6}{T_1 - T_{w1}} \tag{11}$$

The total indirect evaporative cooling efficiency for the direct evaporative stage:

$$\eta_{IEC} = \frac{T_1 - T_3}{T_1 - T_{w1}} \tag{12}$$

The total direct evaporative cooling efficiency for direct evaporative stage:

$$\eta_{DEC} = \frac{T_3 - T_6}{T_3 - T_{w3}} \tag{13}$$

The evaporative efficiencies versus time were plotted in **Fig.11** explaining the efficiency of pads and heat exchangers.

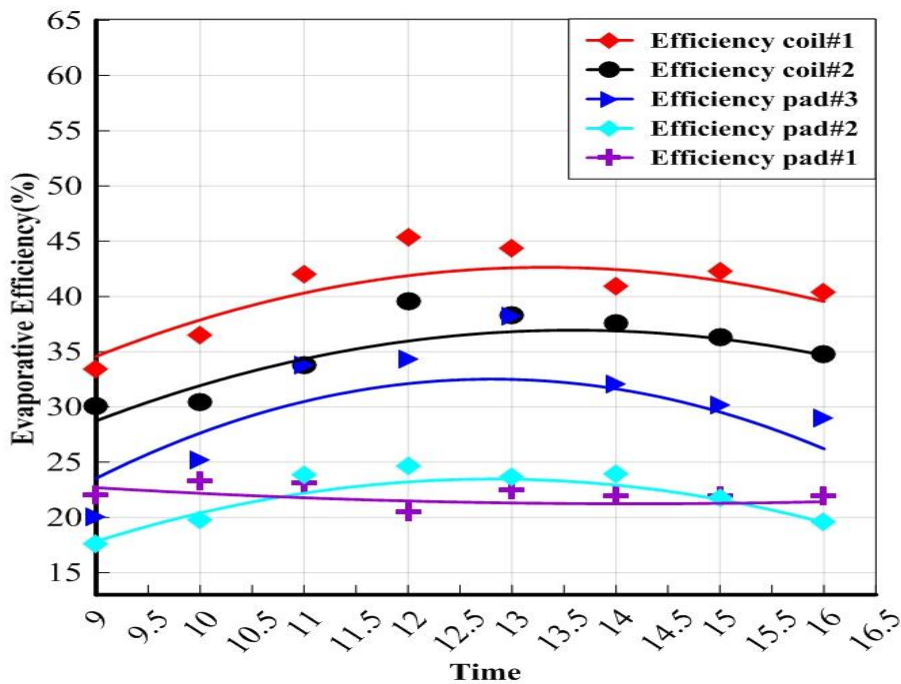


Figure 11. Relation between IDEC Efficiency vs Time (10/8/2017).

The effectiveness increases from pad#1 to pad#3 through evaporative process. **Fig.12** shows this behavior where the air entering the first pad has low wet bulb temperature (WBT) compared to the air entering second and third pads as well as the WBT for the air entering second pad less than the WBT for air entering the third pad. This behavior gives the conclusion that the effectiveness for DEC increased with increasing the relative humidity as well as the increase in WBT through actual pad process while theoretically, the pads process assumed to be constant WBT and the process is called adiabatic. The representation of the process of maximum air temperature in the psychometric chart is shown also in **Fig. 12**. The air pressure drop through the



first heat exchanger is measured about 29 Pa and through the second heat exchanger is measured about 23 Pa whereas the pressure drop through pads is about 6 Pa.

The cooling process was represented also in **Fig. 12**. It is shown that the indirect stage gives the temperature difference (T1-T3) was 16.4°C and the direct stage gives the temperature difference (T3-T6) was 5.6°C.

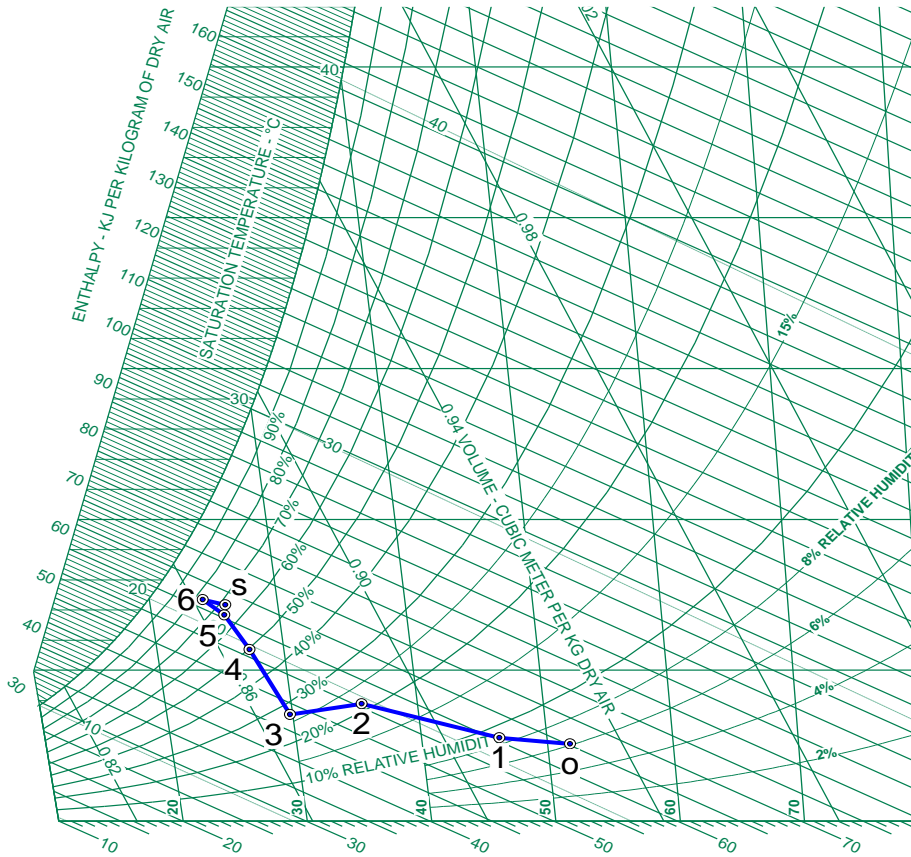


Figure 12. The Indirect-Direct Evaporative Cooling represent on the Psychrometric Chart (10/8/2017).

The efficiency of the first heat exchanger changes from (33.46 to 45.35) % and the second heat exchanger change between (30.04 39.53) % with maximum value for both heat exchangers at 12:30 pm. **Fig. 13** showed that the maximum efficiency reaches 167.1% by using IDEC (two coils with three pads) system while it reduces to 122.72% for the IDEC (one coil with three pads). The efficiency of DEC varies between (59.69-84.36) %. The maximum efficiency for IDEC (two coils with three pads), IDEC (one coil with three pads) and DEC at 13:00 pm whereas The efficiency of IEC varies between (63.49- 84.88) % with a maximum value at 12:00 pm.

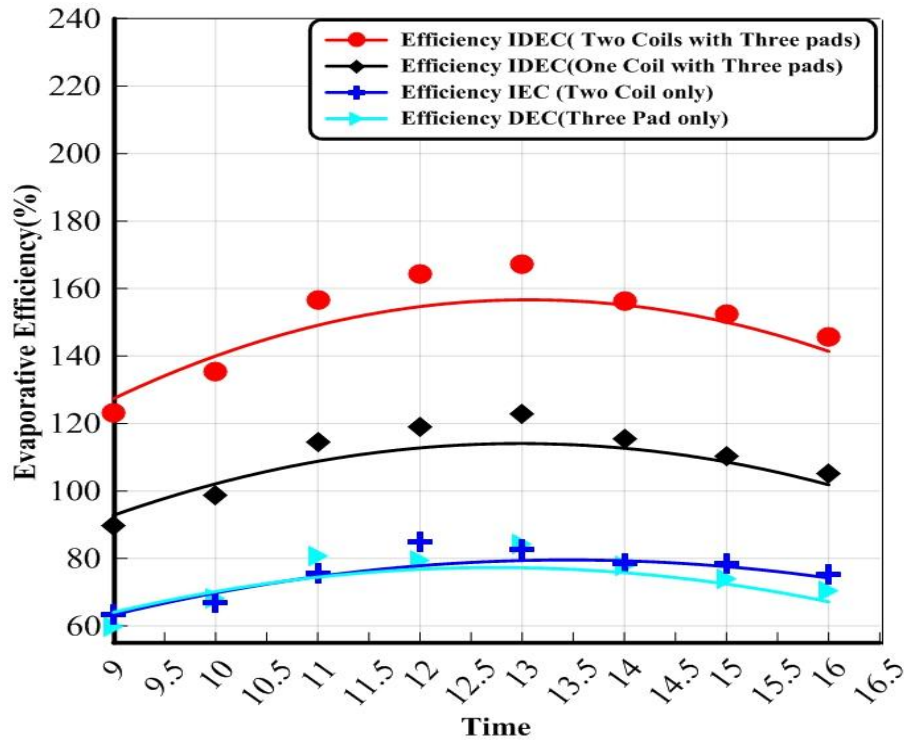


Figure 13. Relation Between Evaporative Efficiency Vs Time (10/8/2017).

Fig.14 and Fig.15 show the relationship between the temperature and evaporative efficiency (η_{IDEC}) variation with a flow rate of 5L/min of groundwater (well water) at a different number of pads. These figures indicate that the temperature and evaporative efficiency variation are increasing with increasing the number of pads by 24% and 42% with increasing the number of pads from 1, 2 and 3 pads, respectively for temperature chart. Also, it is increasing by 14.4% and 23.7% by increasing the number of pads from 1, 2 and 3 pads, respectively for the efficiency chart. Evaporative cooling will be increased by adding any extra pad while the air is not saturated. The description of all cases and the efficiencies were shown in Table 1. The Cases represent the indirect-direct evaporative cooling system (IDEC) two coils with different pad number (each pad 3cm thickness). The first case with 5L/min, the overall evaporative efficiency and indirect evaporative efficiency is 167% and 82.73% respectively with a temperature difference of 26.2°C and three pads. The overall evaporative efficiency and indirect evaporative efficiency reduce to 125% and 81.88% respectively with temperature different 18.3°C with two pads. By using one pad, the overall evaporative efficiency reduces to 118% and indirect evaporative efficiency reduce to 86.57% with a temperature difference of 14.9°C.

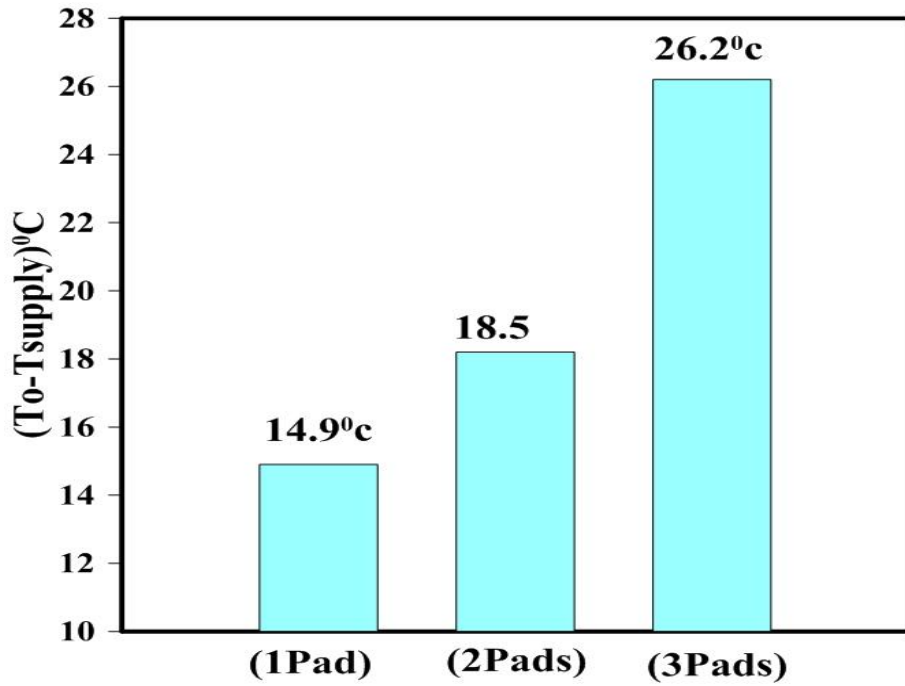


Figure 14. Comparison between Temperature Difference for Cooling System with Well Water Flow Rate 5L/Min and Different Numbers of Pads.

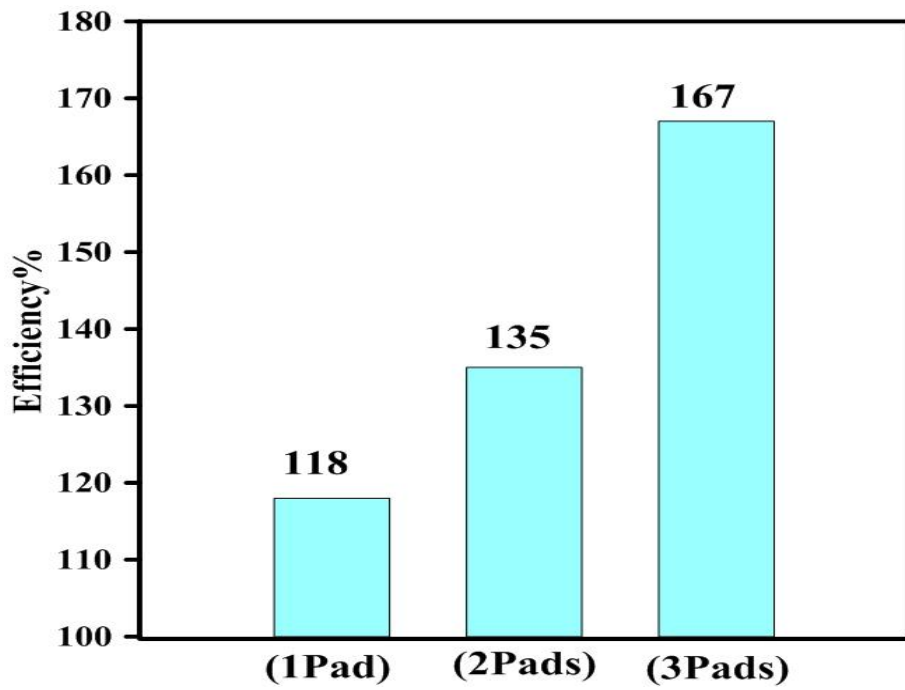


Figure15. Comparison of Overall Evaporative Efficiency for Cooling System with Well Water Flow Rate 5L/min and Different Numbers of Pads.



Table 1. Two Coils with Different Numbers of Pads with 5 L/min well Water Flow rate.

Water flow rate	5 L/min		
No of Pad	1	2	3
η_{IEC}	82.73	81.88	86.57
$\eta_{IEC(max)}$	167	125	118
$T_{out}-T_{supply}$	26.2	18.5	14.9
Time	12:30	11:00	12:30
Date	10/8/2017	7/8/2017	22/8/2017

4. CONCLUSIONS

In this work, an indirect-direct evaporating cooler (IDEC) was installed and studied for air-conditioning the residential room built for this purpose in Baghdad. The well water (geothermal energy) was utilized for cooling. It was shown that the present rig was powerful for comfortable air conditioning and power consumptions.

From the present study it can be concluded the following:

1. Using two heat exchangers with three pads (each pad 3 cm thickness) with 5 L/min well water flow rate instead of one heat exchanger increased IDEC system efficiency to 167%.
2. Increasing of the well water flow rate for IDEC system from 2 L/min to 5 L/min leads to increase the performance of the cooling system and as a result, the overall efficiency was increased about 28.14% and the percentage temperature difference (T_o-T_s) is decreased by about 33.2%.
3. Increasing number of the pad from one pad to three pads (3cm thickness) led to increase the overall efficiency (IDEC) about 29.34%.
4. The maximum temperature difference between the ambient and the supply air reached about 26.2 °C using IDEC (two coils with three pads of 3cm thickness) with 5 L/min well water flow rate.

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NOMENCLATURE

Symbol	Definition	Units
A	area	m^2
d	pipe diameter	m
DBT	air dry bulb temperature	$^{\circ}C$
h	hight of room	m
Hp	Head pump	m
L	length of room	m
LM	latitude-month correction	-
LMTD	log mean temperature difference	$^{\circ}C$
RH%	percentage relative humidity	-
RSL	room sensible load	watt
T1	inlet air temperature to the heat exchanger	$^{\circ}C$
T2	outlet air temperature from the heat exchanger	$^{\circ}C$
T_{w1}	inlet water temperature to the heat exchanger	$^{\circ}C$
T_{w2}	outlet water temperature from the heat exchanger	$^{\circ}C$
V°	air flow rate required	m^3/s
W	width of room	m
WBT	air wet bulb temperature	$^{\circ}C$

I- Greek Symbols

Symbol	Definition	Units
ΔT	the temperature difference between ambient temperature and room temperature	$^{\circ}C$
η_{DEC}	direct evaporative cooling efficiency	-
η_{IDEC}	indirect-direct evaporating cooling efficiency	-
η_{IEC}	indirect evaporative cooling efficiency	-
ν_w	the viscosity of water	m^2/s

II- Abbreviations

DEC	direct evaporative cooling
IDEC	indirect-direct evaporative cooling
IEC	indirect evaporative cooling
PVC	polyvinyl chloride
RPM	revolution per minute