Regular Article

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Enhancement of evaporative cooling system in a green-house by geothermal energy

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Abstract: Greenhouse is one of the most recent agricultural systems that provides an economic resource by increasing production and allowing crops to be grown all year. In Iraq, this approach encounters an impediment during the summer. As a result of the rapid rise in temperatures, greenhouses are becoming increasingly ineffective. In this season, it is unusable. A two-stage evaporative cooling system was used in this study, with one indirect evaporative cooling heat exchanger and three direct evaporative cooling pads. The performance of the proposed indirect–direct evaporative cooling (IDEC) unit with various settings was tested during the summer season in Kirkuk, with dry bulb temperatures ranging from 45 to 50°C. The results reveal that using groundwater increased the IDEC unit's efficiency to 98.3%, compared to 67.5% when using direct evaporative cooling. When covering layers were used, solar intensity entering the greenhouse was lowered from 11.4% for a single layer to 28.4% for two layers with one layer of green mesh. In comparison to ambient circumstances and according to the parameters analyzed, the IDEC system employing groundwater results in a decrease in greenhouse temperature and an increase in greenhouse relative humidity. The IDEC unit was verified using TRANSYS software and experimental measurements from a test greenhouse. For the same ambient temperature, simulated and experimental findings revealed that the simulated temperature is lower than the experimental temperature. The percentage difference in greenhouse temperature between the TRANSYS simulation and experimental measurements reached a maximum of 9.43%.

Keywords: greenhouse, (DEC), ANSYS, geothermal, energy

Nomenclature

A	area (m^{-2})
C_p	specific heat of the air ($J\ Kg^{-1}\ K^{-1}$)
H	maximum high of greenhouse (m)
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
K	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
LMTD	log mean temperature difference (°C)
N	number of air changes per hour (1 h)
Nu	Nusselt number
P	pressure (Pa)
P_{rw}	Prandtl number of water
Q	heat transfer rate (W)
RH	relative humidity
T	temperature (°C)
U	overall heat exchange coefficient ($W\ m^{-2}\ K^{-1}$)
V	air velocity (ms^{-1})
w	specific humidity ($kg\ kg^{-1}$)

Greek symbols

η	evaporative cooling efficiency
$\boldsymbol{\rho}$	density of moist air–air vapor mixture ($kg\ m^{-3}$)
τ	transmittance
ϵs	emissivity
σ	Stefan–Boltzmann constant ($W\ m^{-2}\ K^{-4}$)

Subscript

In	inside greenhouse
a	air
d	dew point temperature
W	water

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Abbreviations

DEC	direct evaporative cooling
IEC	indirect evaporative cooling
IDEC	indirect–direct evaporative cooling

1 Introduction

The weather in Iraq in the long summer season compared with other countries is harsh. This season has high air temperature. An average of 4.7 million hectares in temperate Europe, Asia, and America, 364,000 ha in the Mediterranean, and 156,000 ha in the tropical and subtropical regions are covered by greenhouses, which are covered by plastic films in mild temperatures and glass or rigid plastic in temperate and cold climates [1].

Greenhouse temperature control, which allows producers to enhance crop quality and productivity, refers to the adjustment of the primary environmental factors inside the greenhouse, in order to suit the crop's growth requirements. Recent years have seen a number of studies focusing on greenhouse climate control, which is aided by computing technology via control hardware, such as sensors, controllers, and actuators, which enables the monitoring of temperature, relative humidity (RH), solar radiation, and carbon dioxide (CO_2) concentration, as well as the coordination of equipment operation [2–4]. For instance, the United Arab Emirates' protected crops required between 10.43 and 14.67 kWh/m^2 of cooling energy over the production cycle, while the amount of water needed for evaporative cooling was between 2.6 and 3.5 times that needed for irrigation [5,6]. A two-stage evaporative cooling unit experimental rig is built and put to the test in Kuwait. The efficiency of the IEC/DEC fluctuates over a range of 90–120%, according to the results [7]; the study's foundation is a cooling method that depends on the local climate. The goal of this research is to provide systematic experimental data on the microclimate within the greenhouse during summer season that affects cooling loads, which is a major issue in Iraqi protected agriculture. Also, utilization of an indirect–direct evaporative cooling (IDEC) system for air conditioning the greenhouse will be evaluated.

2 Simulation and theoretical background

The theoretical part of this work is divided into two parts which are theoretical modeling of the problem for cooler and greenhouse and the simulation of the problem using TRANSYS. The indirect–direct evaporative cooler consisted of an indirect stage which is an air-water heat exchanger, and a direct stage which is assembled from three evaporating pads. The water supply to the cooler is from a geothermal well. The greenhouse was modeled using cooling load calculation method. TRANSYS simulation for the present system was done using the equivalent component to the real component used in the work.

3 Indirect evaporating stage

The heat exchanger used in the present work is finned U tube air cooled heat exchanger [8].

$$Q_{\text{IEC}} = \text{UA}(\text{LMTD}), \tag{1}$$

$$\text{LMTD} = \frac{T_{\text{MAX}} - T_{\text{MIN}}}{\ln\left[\frac{Z}{Z + \ln(1 - ZN)}\right]}, \tag{2}$$

where Z and N are given by

$$Z = \frac{T_{F2} - T_{F1}}{T_{\text{MAX}} - T_{\text{MIN}}}, \tag{3}$$

$$N = \frac{T_{\text{MAX}} - \text{T}_{\text{MIN}}}{T_{\text{MAX}} - T_{F1}}, \tag{4}$$

$$U = \sum_{i=1}^{3} R_i = R_1 + R_2 + R_3. \tag{5}$$

The convection heat transfer coefficient for air is proportional to its velocity [9].

$$h_a = 10.45 - V + 10\sqrt{V}. \tag{6}$$

To estimate Nusselt number, the form of the approximating function was assumed for turbulent flow in smooth pipes [10].

$$\text{Nu} = \frac{f/8(\text{Re} - 1{,}000)\text{Pr}}{1 + 12.7\sqrt{f/8}\,(\text{Pr}^{2/3} - 1)}, \tag{7}$$

$$f = (1.82\log\text{Re} - 1.64)^{-2}, \tag{8}$$

$$(2{,}300 \le \text{Re} < 5 \times 10^6) \text{ and } (0.5 < \text{Pr} < 10^6)$$

$$\text{Pr} = -3.68(T) + 17.98(15 \le T \le 57)°\text{C}, \tag{9}$$

$$\mu = -0.48(T) + 2.452(10^{-6})(15 \le T \le 57)°\text{C}, \tag{10}$$

where μ is the dynamic viscosity.

4 Direct evaporating (DE) stage

The DE stage of indirect–direct evaporating cooler employed in this study comprises of three evaporating pads in succession.

For large amount of data, manually employing a psychometric chart is ineffective [11].

Overall efficiency of the system [11]

$$\eta_{DEC} = \frac{T_2 - T_5}{T_2 - T_{F2}}, \tag{11a}$$

$$\eta_{IDEC} = \frac{T_1 - T_5}{1 - T_{F1}}. \tag{11b}$$

Calculating the dew point temperature T_d [11]

$$T_d = \frac{c \times \ln\left(\frac{RH}{100} \times \frac{p_{sm}}{a}\right)}{b - \ln\left(\frac{RH}{100} \times \frac{p_{sm}}{a}\right)}, \tag{12}$$

$$p_{sm} = a \times EXP\left\{\left(\left(b - \frac{Td}{D}\right)\left(\frac{Td}{c + D}\right)\right)\right\}. \tag{13}$$

Define the constants in Equations (12) and (13) were given constants with a maximum inaccuracy of 0.05% and T_d ranging from 0 to 50°C as follows: a = 611.21 Pa, b = 17.368, c = 238.88°C, and D = 234.5°C [11].

$$w = 0.622 \times \frac{p_w}{p - p_w}. \tag{14}$$

5 Cooling load of greenhouse

The possibility of controlling climate parameters in a greenhouse is the most important case of interest in the agriculture production. To assess the greenhouse's cooling demands, our study used a basic energy balance. The energy required to keep the greenhouse's inside temperature at a specified level may be stated as [2]

$$\text{Energy needed} = \sum \text{Heat gain} - \sum \text{Heat loss}, \tag{15}$$

$$\text{Cooling Load} = \left[UAs + \rho c_p N \frac{HA_g}{3,600}\right](T_{max} - T_{in}) + \tau H_g A_g + h_{co,s-i}(T_s - T_d)A_g + \epsilon_g \sigma (T_s^4 - T_{in}^4). \tag{16}$$

6 Modeling using TRANSYS

To verify the experimental results, as well as build an independent extra model for the present work, the greenhouse was analyzed using ANSYS software. The greenhouse system consists of water well, indirect–direct evaporating cooler, and greenhouse unit. Details of each component are given in Figure 1. The built-in types of TRANSYS are used to model these components. The schematic presentation of the present system is given in Figure 2.

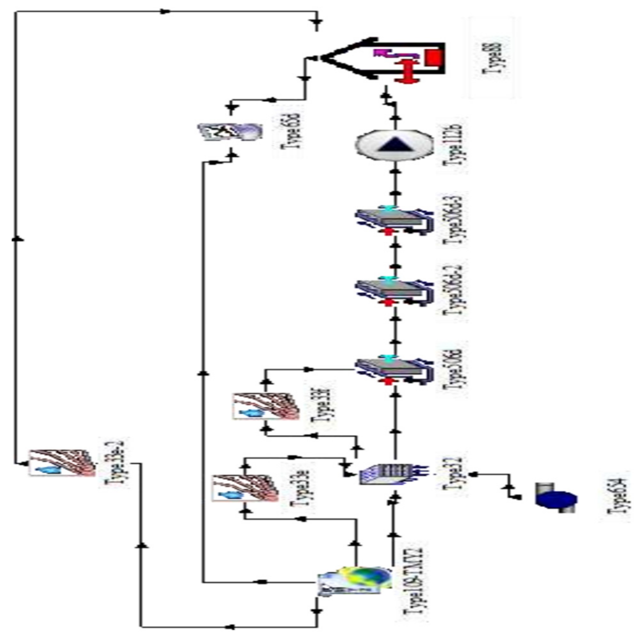

Figure 1: TRANSYS screen capture of the present system.

7 Experimental method

The greenhouse is located in Iraq and was planned, built, and installed there. The provided greenhouse's design is a freestanding even span, which is perhaps the most common and easiest to construct. The inner area configuration consists of a height of 2 m, a gable height of 0.7 m, a south side span angle of 26.6°, a north side span angle of 35°, a length of 2.5 m, a width of 2.0 m, a floor surface area of 5.0 m^2, and a volume of 11.2 m^3. These are the geometric characteristics of the greenhouse form model. The greenhouse was constructed using

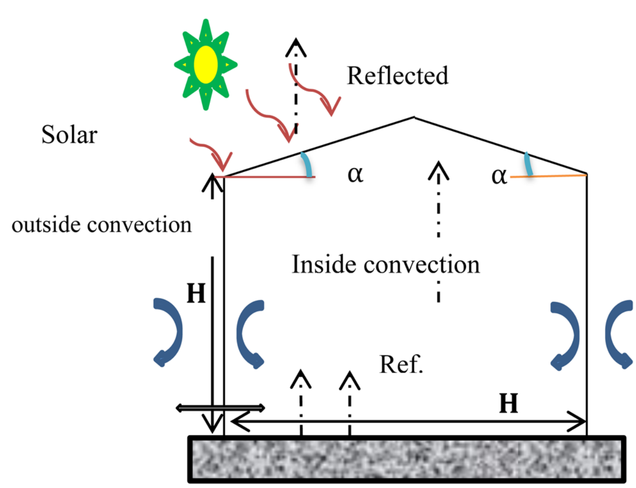

Figure 2: The greenhouse model.

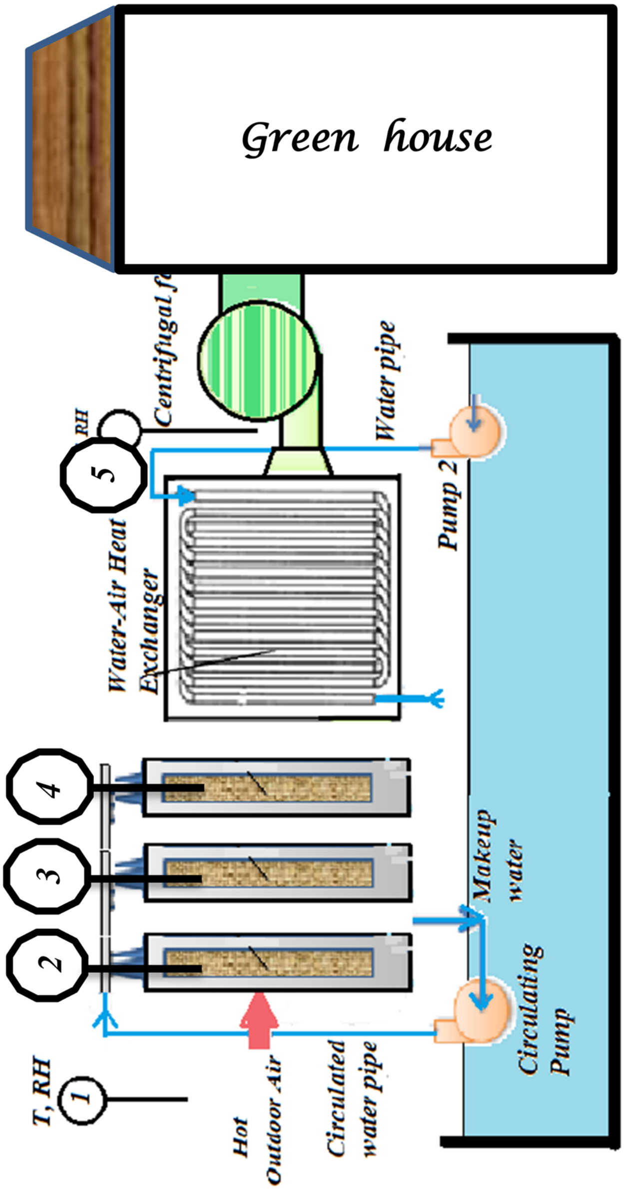

Figure 3: Experimental rig.

50 mm × 50 mm wooden poles. A double-polyethylene layer 300 m thick with a 5 cm gap covers the experimental greenhouse. It was oriented east-west, with the southern longitudinal axis facing the sun's beams. On the west side is the cooler, and on the east side is the door. The intended greenhouse is depicted schematically in Figure 3. The following four types of coverings were tested: a) a single sheet of polyethylene film serves as cover 1, b) cover 2: a double-layered polyethylene film, c) cover 3: a green shade layer between two layers of polyethylene film, and d) cover 4: a double-layer of polyethylene film with a Utrecht Corrugated Cardboard with 3 cm holes for incident sunlight.

8 Results and discussion

8.1 Solar intensity through greenhouse covers

The solar intensity through direct and shadows for the days of work was measured and plotted in Figure 4. It was discovered that the sun intensity peaks at around 1,000 W/m^2 at 1:00 p.m. Because the light is seen by green mesh as well as a double layer of polyethylene, cover3 produces a larger decrease in light intensity, whereas cover1 delivers a smaller decrease in light intensity for a single layer of polyethylene. A double layer of polyethylene is sandwiched in between.

8.2 Geothermal well temperature

In summer, the temperature of the geothermal well was monitored and plotted hourly against the ambient temperature, as shown in Figure 5. The temperature of the

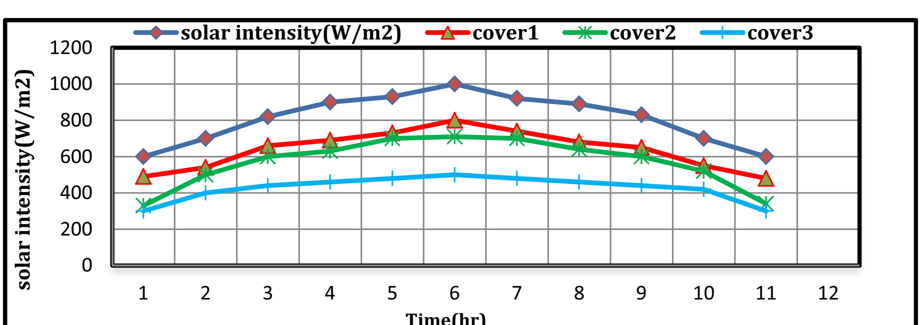

Figure 4: Solar intensity green-house cover.

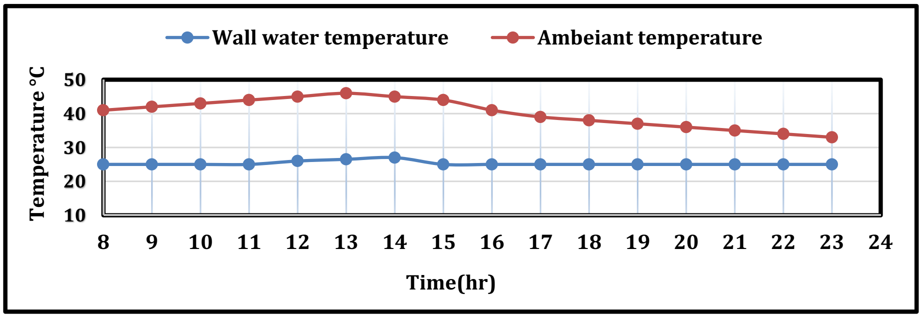

Figure 5: Water and ambient temperature with time.

groundwater varies between 25 and 27°C, while the surrounding temperature at the same time is 45.5°C on a summer day. It concludes that, when compared to the ambient temperature change, groundwater temperatures have a minimal seasonal fluctuation. This is because the temperature change is less affected by the ambient temperature as the depth of groundwater increases. Throughout the year, seasonal temperature changes fluctuated by around 3°C. This phenomenon will allow groundwater to be used for cooling in the summer.

8.3 Relative humidity

As seen in Figure 6, the relative humidity was at its lowest point (about 10%). Because of evaporation in soil and agriculture, the humidity within the greenhouse is still higher than the outside circumstances. Evaporation in soil and agriculture causes the relative humidity in the greenhouse to be higher than in ambient settings.

8.4 Effect of design parameters on the overall efficiency

When comparing traditional DEC to the presented IDEC utilizing well water as a cooling-fluid in two stages, as shown in Figure 7, the evaporative efficiency increased from 67.5 to 98.3%. IDue to the low temperature air entering the greenhouse, the difference between the temperature of air entering and exiting the evaporative cooler is increased.

8.5 Performance of indirect–direct evaporative cooler

Figure 8 shows the temperature and humidity measurements for the cooling system, which comprises one air-water heat exchanger acting as an IEC and three pads acting as a DEC. It was observed that the relative humidity decreased to a low value of around 7% as the temperature increased, reaching a maximum of 48°C (T1) at noon. Through the cooling procedures for the indirect–direct cooler stages, the temperature was lowered to 22°C by noon.

8.6 TRANSYS simulation

Figure 9 shows that the temperature variation was similar to that of the ambient temperature (*T*1) because of the theoretical assumption that the processes were not

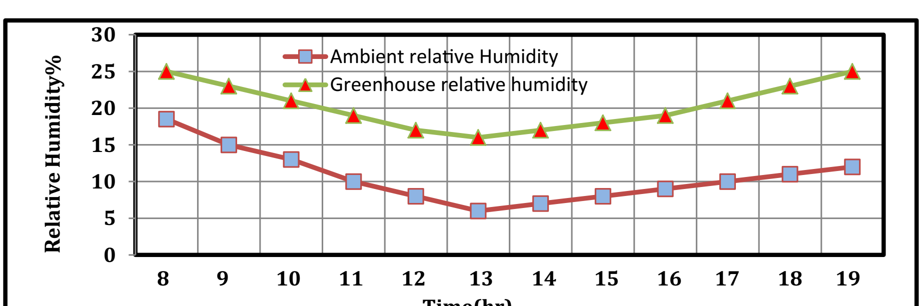

Figure 6: Relative humidity of green-House and ambient conditions during summer.

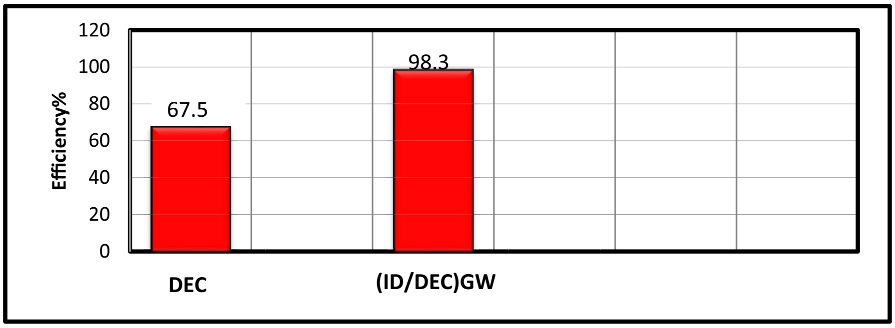

Figure 7: Compression between DE efficiency and presented IDE efficiency with geothermal water.

affected by environments and unideal behavior through the experimental work. The condensation, fogging, heat transfer through the cooler duct, non-uniform distribution of evaporating water flow, and other parameters affected the properties of air through the processes.

Assumptions

1. Heat transfer through the direct stage (air-water heat exchanger) is done without heat loss.
2. Constant moisture content through the IEC.
3. The DEC is done at constant wet bulb temperature.

8.7 The Prandtl number and viscosity of water

The results from equations of these parameters which were fitted in equations (9) and (10) were plotted against temperature with the values from Wojtkowiak [11] in

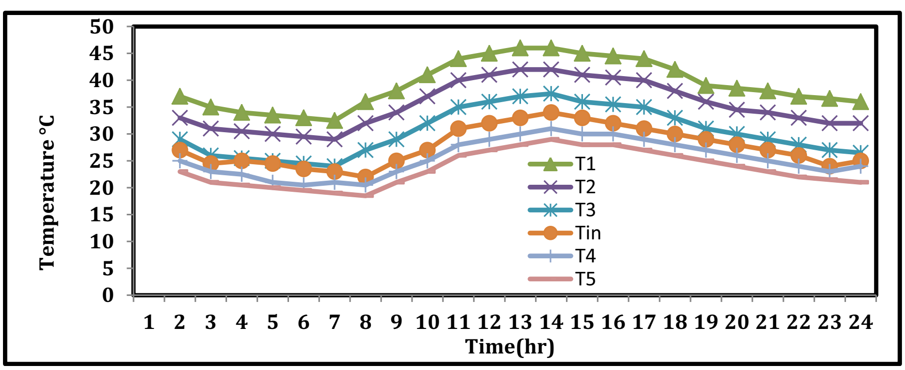

Figure 8: Process temperature in summer as shown in Figure 3.

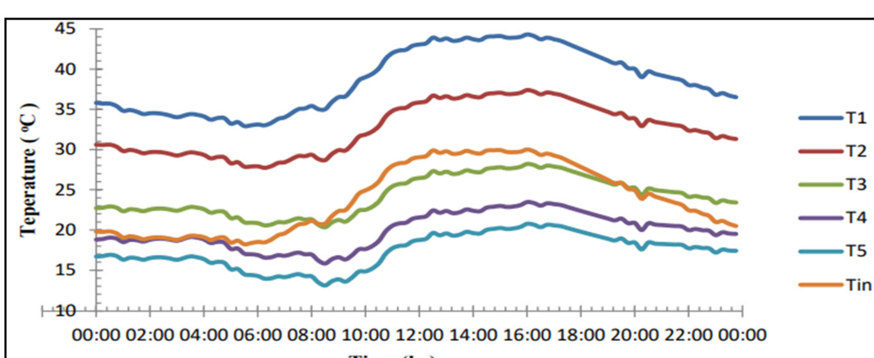

Figure 9: Ambient, process, and inside temperatures of green-house using **TRANSYS** simulation.

Figures 10 and 11, respectively. It was shown that the results from the present equation are in fair agreement with the author. The errors for using these equations do not exceed 1.63% for the Prandtl number and 3.9% for viscosity. These conclude that using this equation is applicable for the range of air-conditioning work in summer (15–57°C).

8.8 Effect of number of the pads on evaporating cooling

The comparison of evaporative efficiency with different numbers of pads is shown in Figure 12. It was discovered that increasing the number of pads resulted in higher evaporative efficiency. When the extra pad is added

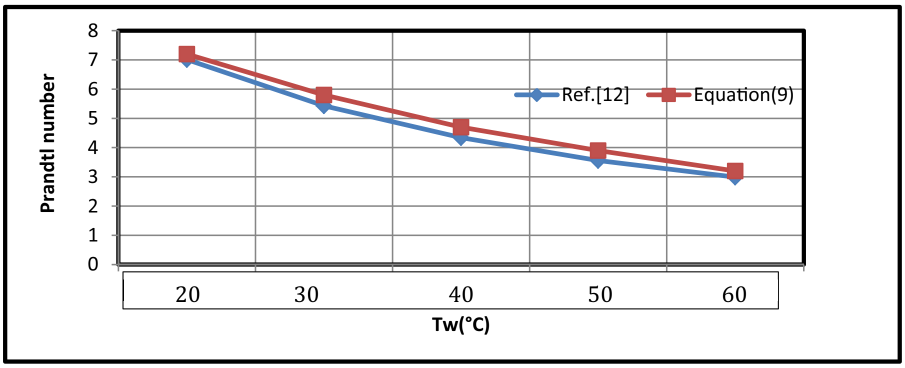

Figure 10: Prandtl number of water with temperature.

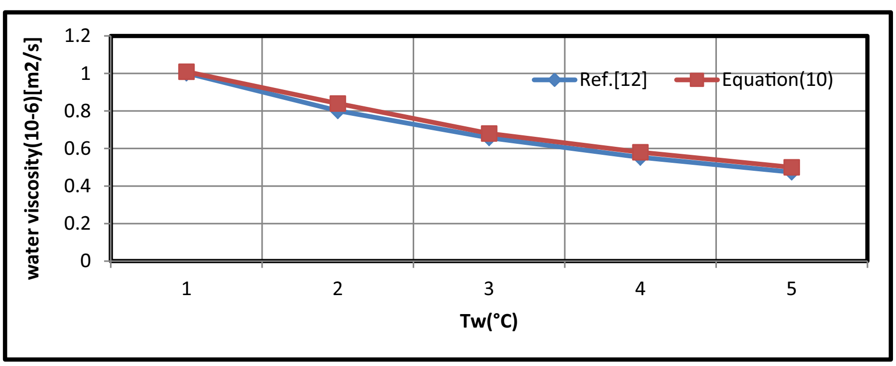

Figure 11: Viscosity of water vs temperature.

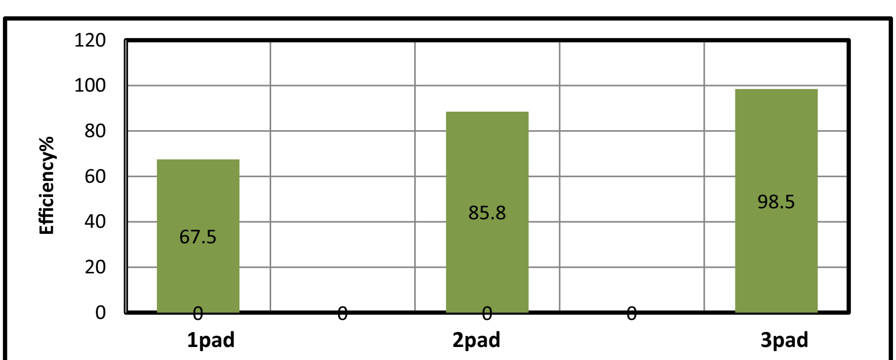

Figure 12: Evaporative efficiency with different pads.

while the air is not saturated, the evaporation cooling increases.

9 Conclusion

An indirect–direct evaporating cooler was created and tested for air-conditioning the greenhouse erected for this purpose in Kirkuk city, as a result of the current study.

1. The efficiency of DEC with three pads and geothermal well water is 67.5%.
2. Using an IDEC strategy with geothermal water as a cooling fluid well, evaporative cooling efficiency was enhanced to 98.3%.
3. During summer, the ambient temperature had minimal effect on the temperature of the groundwater. Throughout the year, the seasonal temperature changes fluctuated by around 3°C.
4. Due to evaporation in soil and agriculture, the relative humidity in the greenhouse is higher than in ambient settings.
5. The simulated temperatures using **TRANSYS** are lower than the real temperatures by 2.3 maximum with the percentage of 9.43%.
6. It was shown that the results from the presented equations (9) and (10) are in fair agreement with the author. The errors for using these equations do not exceed 1.6% for the Prandtl number and 3.9% for viscosity. These conclude that using this equation is applicable for the range of air-conditioning work in summer (15–57°C).
7. Adding an extra pad while the air is not saturated causes the evaporative cooling to increase.
8. Indirect evaporative cooling works on the same principle as direct evaporative cooling lowering air temperature by water Evaporation. The major difference in an indirect system is that it uses an heat exchanger to cool the air supplied to the working space.

Conflict of interest: The authors declare that they have no conflict of interest.

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