Modeling of the Seawater Greenhouse Systems

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Abstract: The Seawater Greenhouse system uses sunlight, seawater and air to provide freshwater and cooled and humid air, so that in addition to provide the water required for greenhouse, supply more sustainable environmental condition from cultivation of crops in arid coastal regions. In this system ambient air is passed through the two evaporative cooling pads, which plant growth area is placed between those pads, by fans that placed end of the building, and then returned taking humidity on the tube-and-fin condenser. In order to decrease the entrance heating load to the plants, use pipe arrays to provide shade. This paper tries to describe simulation the Seawater Greenhouse considering condition of the Bandar Abbas City in IRAN. Different cycles of Sea water greenhouse, including 6 arrangements, was modeled and obtained the behavior of each cycle one of the results of this paper is presenting an enhanced model to earn more produced water. Next, optimal working conditions are specified for absorption chillers and after that, the effect of the thermoeconomic parameter on the maximum thermoeconomic criterion, coefficient of performance and the specific refrigeration load corresponding to the maximum value of the thermoeconomic criterion are investigated.

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Nomenclature

D *Pipe diameter*...*m*
E *Pipe thickness* ....*m*
F *Seeing surface*..
g *Acceleration due to gravity*...................... $m{\cdot}s^{-2}$
h *enthalpy* .... $kjkg^{-1}$
h *heat transfer coefficient* .... $wm^{-2}k^{-1}$
I *solar radiation intensity*........................... wm^{-2}
k *Thermal conductivity*........................... $wm^{-1}k^{-1}$
M *mass* ....*kg*
M^0 *flow rate*... $lits^{-1}$
flow rate... $m^3{\cdot}s^{-1}$
Nu *Nusselt number*...
p *pressure* ....*pa*
pr *Prandtl number* ....
Q *Heat transfer*..*kj*
Re *Reynolds number*..
T *Temperature*..*k*
U *Specific energy*....................................... $kjkg^{-1}$
V *velocity* .... $m{\cdot}s^{-1}$
V *viscosity* .... $m{\cdot}s^{-1}$ *1*
........................*Entering air to first evaporator*
....

ω *stefan-boltzmann constant* .... $wm^{-2}k^{-4}$

V *transmittance* .... $m{\cdot}s^{-1}$ *12*
..................*Entering Water to first evaporator*
....
1 *Entering air to first evaporator*.......................
2 *Entering Water to first evaporator*..................
3 *Water out from first evaporator* ....
4 *Air out from first evaporator*...........................
5 *Entering Water to pipes array*.........................
7 *Entering air to growing space*.........................
8 *Air out from roof space*...................................
9 *Air out from growing space* ....
10 *Entering water to second evaporator* ....
11 *Entering air to second evaporator* ....
12 *Water out from second evaporator*..................
13 *Air out from second evaporator* ....
14 *Entering water to condenser* ....
15 *Water out from condenser*...............................
16 *water production*...
17 *Air out from condenser*..................................
α *absorptance* ....
ε *Emittance*..
φ *Relative humidity*...
ω *Water content*..

1. Introduction

The earliest solar distillation plant on record was designed and built in 1872 by Charles Wilson in Chile (Talbert et al. 1970). It was further developed at the University of Arizona in 1961 in cooperation with the Georgia Institute of Technology and the University of Sonora, Mexico at Puerto Peñasco,New Mexico. Hamed and etal in 1993 Farid in 1999 and Goosen and etal in 2000 had presented a well detailed study about sun fresh water making plans and policies. But, the seawater Greenhouse history returned to 1991. The first experimental project started in Tenerife in 1994. This prototype Seawater Greenhouse was planned in England and constructed in Tenerife.

The increasing water requesting growth and water providing resources shortage are two certain and predictable problems in 21 century. Now, the great areas in the world suffer from drought. The deserts are developing and in comparison, raining has a fixed movement. While water requesting have been two times in present 20 years, request forwarding from refreshing resources amount is following at the same way. About 70% total water uses are in farming and then water crisis can be review in so close relationship with food materials producing and economy development and creating. Custom and traditional farming which just need few hundred liters water just produces one kg output and it is because of this farming style inefficiency in water management. The farming and its increasing water requesting will be an important pressure point in which seawater Greenhouse will help using and incorporating natural processes in order to provide low-cost resolution for presenting permanent and similar model in arid coastal regions to decrease this pressure. Seawater Greenhouse provides an ambient in which plants sweating is as low as possible. So, Greenhouse produces its needed sufficient water during sun distillation operation.

2. Modelling and Optimisation

In Seawater Greenhouse, the planting place is between two evaporative cooling pads which the first one is responsible for providing humid and cool ambient and the second pad performs air saturation operation as much as possible. In the greenhouse, for decreasing sun shining load was used pipe arrays carrying seawater to shadowing. These pipes feed the second evaporative pad through water which heated by the sun. And so that help humidify the air.

The first evaporator:

The first stage in Greenhouse simulation is the study of the evaporative cooling pad in the front of greenhouse. Energy and mass balance for evaporator gives:

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_4 h_4 \tag{1}$$

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3 + \dot{m}_4 \tag{2}$$

The entrance air mass obtained with equation 3:

$$\dot{m}_{Air} = \frac{\dot{m}_1}{1+\omega_1} \tag{3}$$

The evaporative water amount will take from:

$$\dot{m}_4 - \dot{m}_1 = \dot{m}_{Air}(\omega_4 - \omega_1) \tag{4}$$

$$h_1 = f(T_1, P_{Ambient}, \omega_1) \tag{5}$$

$$\omega_1 = f(T_1, P_{Ambient}, \varphi_1) \tag{6}$$

$$h_2 = f(T_2, P_{Ambient}) \tag{7}$$

$$h_3 = f(T_3, P_{Ambient}) \tag{8}$$

$$T_4 = f(h_4, P_{Ambient}, \varphi_4) \tag{9}$$

$$\omega_4 = f(T_4, P_{Ambient}, \varphi_4) \tag{10}$$

In this stage, the evaporator takes humid by passing the humid surface and so getting saturation and results visible drop temperature.

The growth area:

Air after passing through the evaporator enters the growth space. Before air entering in plants growth space, part of it directs to the space in up. This part has an important role in freshwater production and simulate as follow:

The roof:

$$\alpha_{Body} I - h_{Out}(T_{Roof} - T_1) - h_{Up}(T_{Roof} - T_{Up}) - F_{Roof.Pipe}.\sigma.\varepsilon_{Body}(T_{Roof}^4 - T_{Pipe}^4) - F_{Roof.Sky}.\sigma.\varepsilon_{Body}(T_{Roof}^4 - T_{Sky}^4) = 0 \tag{11}$$

The left:

$$\alpha_{Body} I - h_{Out}(T_{Left} - T_1) - h_{Down}(T_{Left} - T_{Down}) - F_{Left.Pipe}.\sigma.\varepsilon_{Body}(T_{Left}^4 - T_{Pipe}^4) - F_{Left.Sky}.\sigma.\varepsilon_{Body}(T_{Left}^4 - T_{Sky}^4) - F_{Left.Floor}.\sigma.\varepsilon_{Body}(T_{Left}^4 - T_{Floor}^4) = 0 \tag{12}$$

The right:

$$\alpha_{Body} I - h_{Out}(T_{Right} - T_1) - h_{Down}(T_{Right} - T_{Down}) - F_{Right.Pipe}.\sigma.\varepsilon_{Body}(T_{Right}^4 - T_{Pipe}^4) - F_{Right.Sky}.\sigma.\varepsilon_{Body}(T_{Right}^4 - T_{Sky}^4) - F_{Right.Floor}.\sigma.\varepsilon_{Body}(T_{Right}^4 - T_{Floor}^4) = 0 \tag{13}$$

Pipes carrying seawater:

$$\alpha_{Pipe}.\rho_{Body}.I - h_{Pipe}(2T_{Pipe} - T_{Up} - T_{Down}) - F_{Pipe,Left}.\sigma.\varepsilon_{Pipe}(T_{Pipe}^4 - T_{Left}^4) - F_{Pipe,Right}.\sigma.\varepsilon_{Pipe}(T_{Pipe}^4 - T_{Right}^4) - F_{Pipe,Floor}.\sigma.\varepsilon_{Pipe}(T_{Pipe}^4 - T_{Floor}^4) - F_{Pipe,Roof}.\sigma.\varepsilon_{Pipe}(T_{Pipe}^4 - T_{Roof}^4) - \frac{2T_{Water} - T_{Up} - T_{Down}}{\frac{1}{h_{Water}} + \frac{e}{k}} \quad (14)$$

The Floor:

$$\alpha_{Floor}.(\rho_{Body}.\rho_{Pipe} + 2\rho_{Body})I - h_{Down}(T_{Floor} - T_{Down}) - F_{Floor,Left}.\sigma.\varepsilon_{Floor}(T_{Floor}^4 - T_{Left}^4) - F_{Floor.Right}.\sigma.\varepsilon_{Floor}(T_{Floor}^4 - T_{Right}^4) - F_{Floor,Pipe}.\sigma.\varepsilon_{Floor}(T_{Floor}^4 - T_{Pipe}^4) \quad (15)$$

The Greenhouse out air h:

$$h_{Out} = \frac{Nu_{Out}.k_{Out}}{L} \quad (16)$$

$$Nu_{Out} = (0.037\,\mathrm{Re}_{L,Out}^{4/5} - 871)\,\mathrm{Pr}_{Out}^{1/3} \quad (17)$$

$$\mathrm{Pr}_{Out} = f(T_1) \quad (18)$$

$$\mathrm{Re}_{L,Out} = \frac{V_{Out}.L}{\mu_{Out}} \quad (19)$$

$$\mu_{Out} = f(T_1, P_{Ambient}, \omega_1) \quad (20)$$

$$V_{Out} = \rho_1.\dot{m}_1 \quad (21)$$

$$\rho_1 = f(T_1, P_{Ambient}, \omega_1) \quad (22)$$

$$k_{Out} = f(T_1, P_{Ambient}, \omega_1) \quad (23)$$

The passing water h from the pipes:

$$h_{Water} = \frac{Nu_{Water}k_{Water}}{D_{Pipe}} \quad (24)$$

$$Nu_{Water} = 3.66 + \frac{0.0668\frac{D_{Pipe}}{L}\mathrm{Pr}_{Water}\mathrm{Re}_D}{1 + 0.04(D_{Pipe}\mathrm{Pr}_{Water}\frac{\mathrm{Re}_D}{L})^{2/3}} \quad (25)$$

$$\mathrm{Pr}_{Water} = f(T_{Water}, P_{Ambient}) \quad (26)$$

$$\mathrm{Re}_D = \frac{4\dot{m}_{10}}{\pi D_{Pipe}\mu_{Water}} \quad (27)$$

$$\mu_{Water} = f(T_{Water}, P_{Ambient}) \quad (28)$$

$$k_{Water} = f(T_{Water}, P_{Ambient}) \quad (29)$$

In this stage, by taking two control volumes around the Greenhouse up and down space that separating by the pipes carrying seawater, we have the following equations.

$$\dot{m}_6h_6 + h_{Up}(T_{Roof} - T_{Up}) + h_{Pipe}(T_{Pipe} - T_{Up}) - \dot{m}_8h_8 = 0 \quad (30)$$

$$\dot{m}_7h_7 + h_{Down}(T_{Floor} + T_{Left} + T_{Right} - 3T_{Down}) + h_{Pipe}(T_{Pipe} - T_{Down}) - \dot{m}_9h_9 = 0 \quad (31)$$

$$T_8 = f(h_8, P_{Ambient}, \omega_8) \quad (32)$$

$$T_9 = f(h_9, P_{Ambient}, \omega_9) \quad (33)$$

The Greenhouse mean temperature at up and down space and the mean temperature of the pipes passing water are defined according to 34, 35 and 36:

$$T_{Up} = \frac{1}{2}(T_6 + T_8) \quad (34)$$

$$T_{Down} = \frac{1}{2}(T_7 + T_9) \quad (35)$$

$$T_{Water} = \frac{1}{2}(T_5 + T_{10}) \quad (36)$$

The entering air divided into two branches that flowing down branch has the duty of humidification and cooling of the ambient and the up branch has the duty of by removing the heat gained from sun by pipe arrays and applying it increasing humidity capacity of air in exit. These two branches were mixed by near the second evaporator and caused increasing air temperature and moisture capacity. These combinations write as follow:

$$\varphi_{11} = f(T_{11}, P_{Ambient}, \omega_{11}) \quad (37)$$

$$h_{11} = f(T_{11}, P_{Ambient}, \omega_{11}) \quad (38)$$

The second evaporator:
This evaporator analyzes such as the first one

Condenser:
According figure 3, the governing equations are as following:

$$\dot{m}_{13}h_{13} + \dot{m}_{14}h_{14} = \dot{m}_{15}h_{15} + \dot{m}_{16}h_{16} + \dot{m}_{17}h_{17} \quad (39)$$

$$\dot{m}_{13} - \dot{m}_{17} = \dot{m}_{Air}(\omega_{13} - \omega_{17}) \quad (40)$$

$$\dot{m}_{13} = \dot{m}_{16} + \dot{m}_{17} \quad (41)$$

$$h_{14} = f(T_{14}, P_{Ambient}) \quad (42)$$

$$T_{15} = f(h_{15}, P_{Ambient}) \quad (43)$$

$$h_{16} = f(T_{16}, P_{Ambient}) \quad (44)$$

$$\omega_{17} = f(T_{17}, P_{Ambient}, \varphi_{17}) \quad (45)$$

$$h_{17} = f(T_{17}, P_{Ambient}, \omega_{17}) \quad (46)$$

Finally, all of these equations stimulate and solved by EES program.

3. Result and conclusion

Bandar Abbas have chosen as stimulation reference, and was simulated based on the following the following amounts:

$$P_{Ambient} = 100\,KPa, V_{Out} = 10\,m/s,$$

$$I = 250\,W/m^2, L = 42m, \varphi = 0.64,$$

$$\dot{m}_1 = 20\,kg/s, \dot{m}_2 = 3\,Lit/s$$

Figure 1 shows the difference temperature between the inlet and outlet of the first evaporator as function of the mass flow rate of entrance air and the relative humidity of entrance air. With increasing mass flow rate, Re and h was increased and it caused more evaporation and the temperature of air was decreased. Figure 2 shows the difference temperature between the inlet and outlet of the first evaporator as function of the mass flow rate of sea water and the relative humidity of entrance air. As shown in the figure, the more increasing mass flow, the more decreasing temperature drop. Furthermore, the more increasing humid, the more decreasing temperature difference.

Figure 3 shows water producing water according to entrance air mass flow and various air humid. As you see in this figure, entrance air increasing has affected water producing tendency increasingly and has had an important step toward its decrease.

Figure 4 shows water producing mass flow based on seawater mass flow and various airs humid. As have shown seawater mass flow increasing causes temperature dropping, then more warm air goes to the roof and its entrance will be warmer and caused the exit water will be warmer, this increases water inclination to evaporation and humid absorbing more. These events in addition to warmer air gets condense better in condenser will increase producing water in it and also we see clearly increasing in seawater mass flow will increase the producing water.

Figure 5 shows Greenhouse floor temperature based on entering air mass flow and various air humid. As have considered, increasing entrance air mass flow will decrease the outlet temperature of the first evaporator, and it results in more heat transfer to greenhouse floor and decrease its temperature. In addition, entrance air mass flow increase affects Re and Nu and increasing h and absorbs multiple heat, so we can say the higher humid will be as the same as more soil temperature. As we see in this figure, entrance mass flow increasing has decrease heat, and more humid, will increase Greenhouse floor in a certain air mass flow.

Figure 6 shows the temperature of Greenhouse floor as a function of seawater mass flow and various airs humid. It is cleared that the increasing water producing mass flow has increased soil temperature. It happens more in much humid.

4. Conclusion

The difference cycles was simulated here to find the optimum cycles in this Greenhouse. The stimulations were ruined according the Bandar Abbas conditions. The first cycle which has shown by C1 in the figures, is the simplest one and the changes in other cycles are based on this plan. C2 is a plan for decreasing the greenhouse floor temperature. The air which exits the condenser will be passed the under of the growth space in order to decrease Greenhouse floor temperature. C3 is a similar plan with the same goal by another approach. In this cycle, the water which exit the first evaporator is passed the under of Greenhouse floor space, like previous plan, for decreasing the temperature. C4, C5 and C6 have considered in order to low cost and each of them includes these changes: condenser feeding from the first evaporator exit water, pipes array feeding through condenser exit and finally pipes array feeding by the second evaporator exit. Now, we study these graphs in detail: Considering present cycles we can sea with increasing humidity the water producing was increased. Another important result will obtain from this graph is:m16: C3>C2>C6>C5>C4>C1

Figure 7 shows water producing in different cycles according to various air humid, and describe cycle 3 is the best in water production and providing pleasure heat for greenhouse floor (in this way and through thermal transmitting increasing to the air produces water) and also says condenser feeding through exit water from operator just low cost and hasn't so profits in water producing.Figure 8 shows water producing in different cycles based on various entrance air mass flow rate: This graph interpretation is like graph 7 and the alone point which isn't mentioned is in all cycles increasing entrance air mass flow equal water producing. Figure 9 shows the location of different places in basic cycle.

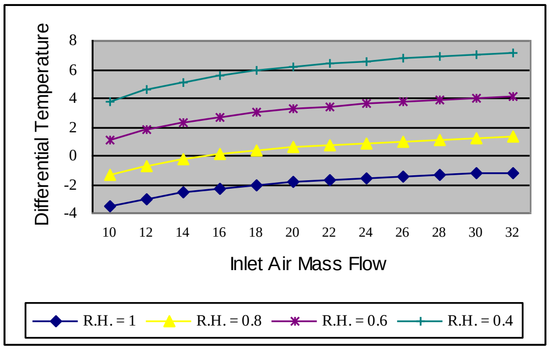


Fig 1- effect of heat inlet mass flow in Diff. T.

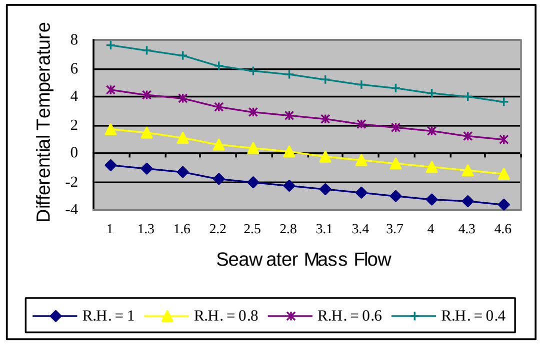


Fig 2- effect of sea water mass flow in Diff. T

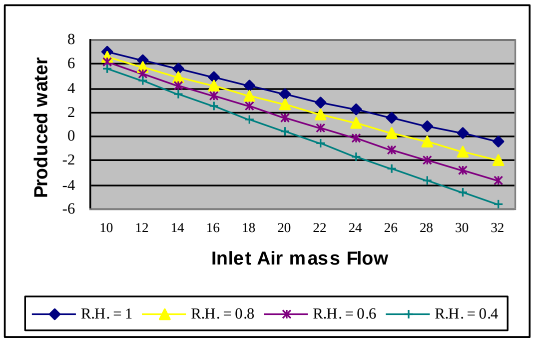


Fig 3- effect of inlet mass flow in produced water

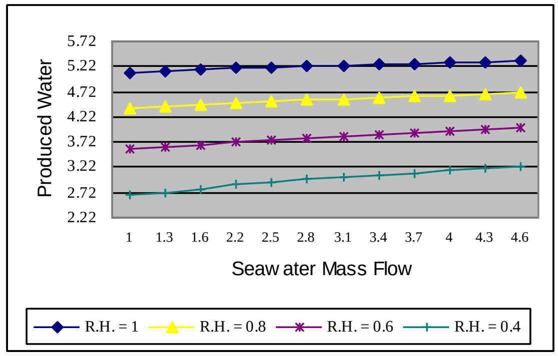


Fig 4- effect of sea water mass flow in produced water

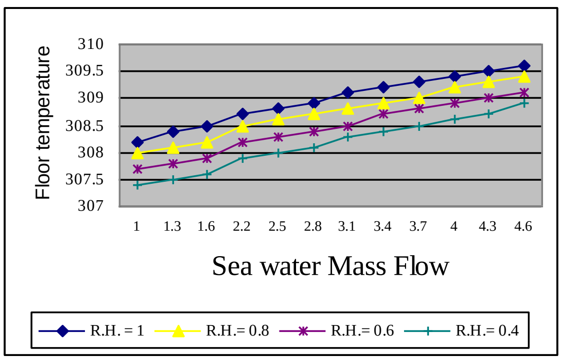


Fig 5- sea water mass flow in floor temp.

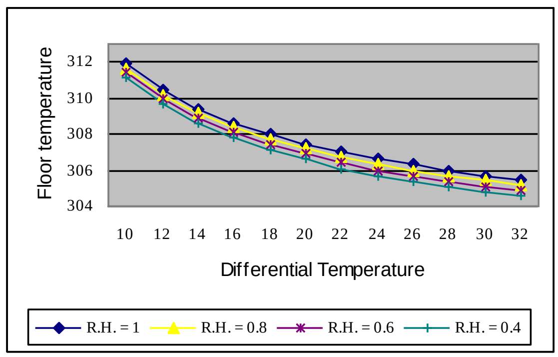


Fig 6- Diff. Tem. in Floor Temperature

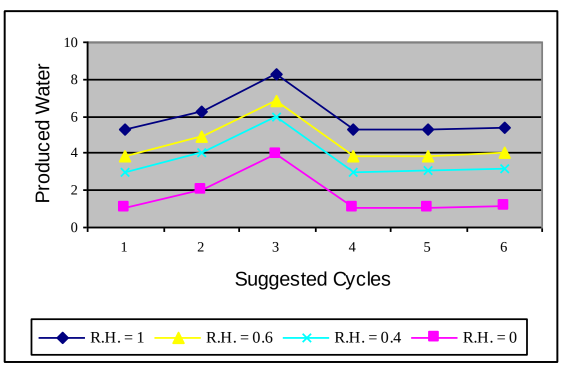


Fig 7- effect of suggested cycles in produced water

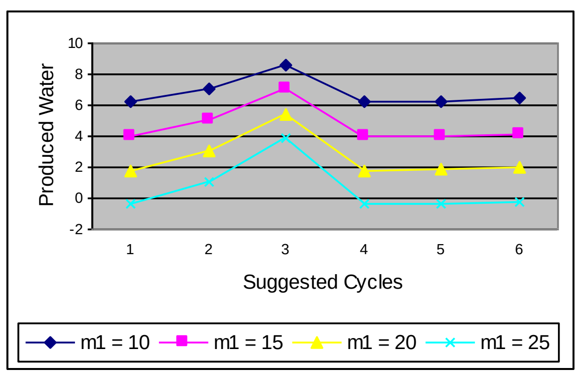


Fig 8- effect of suggested cycles in produced water in mass

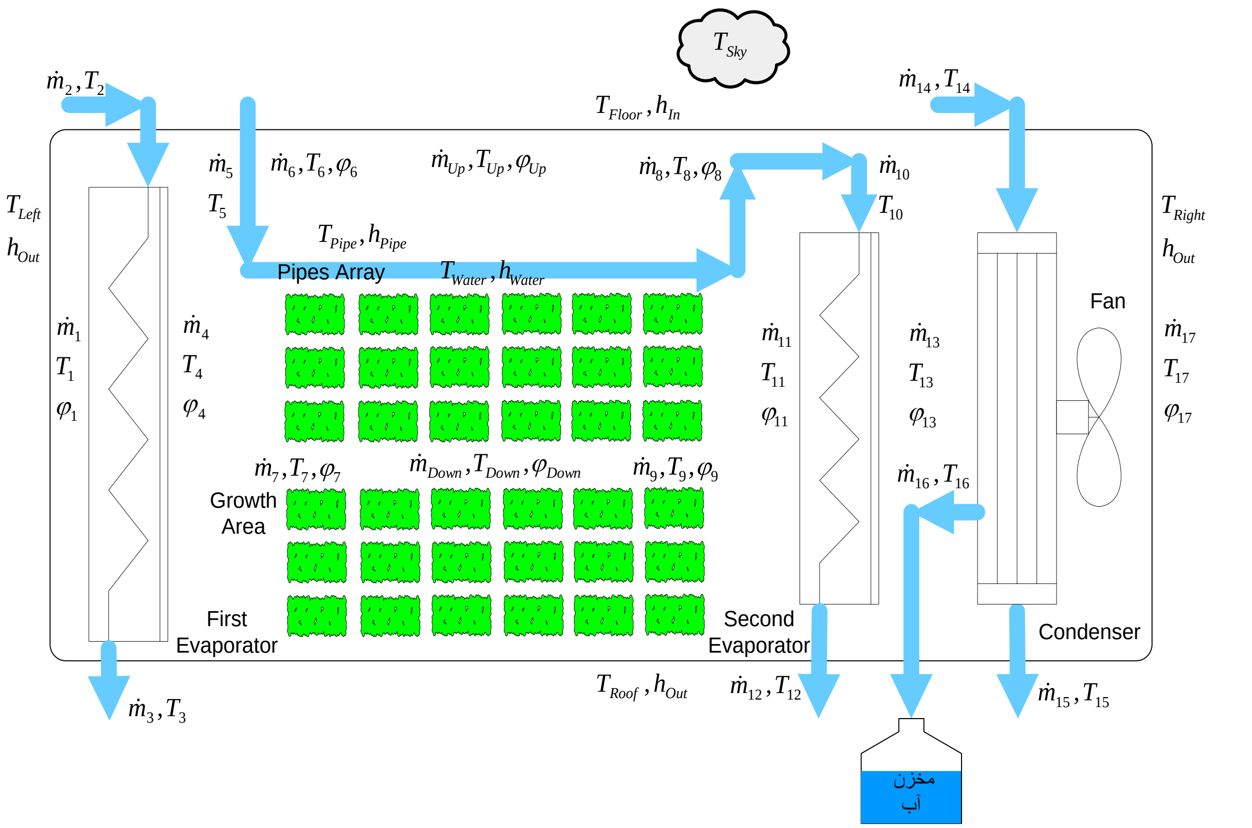
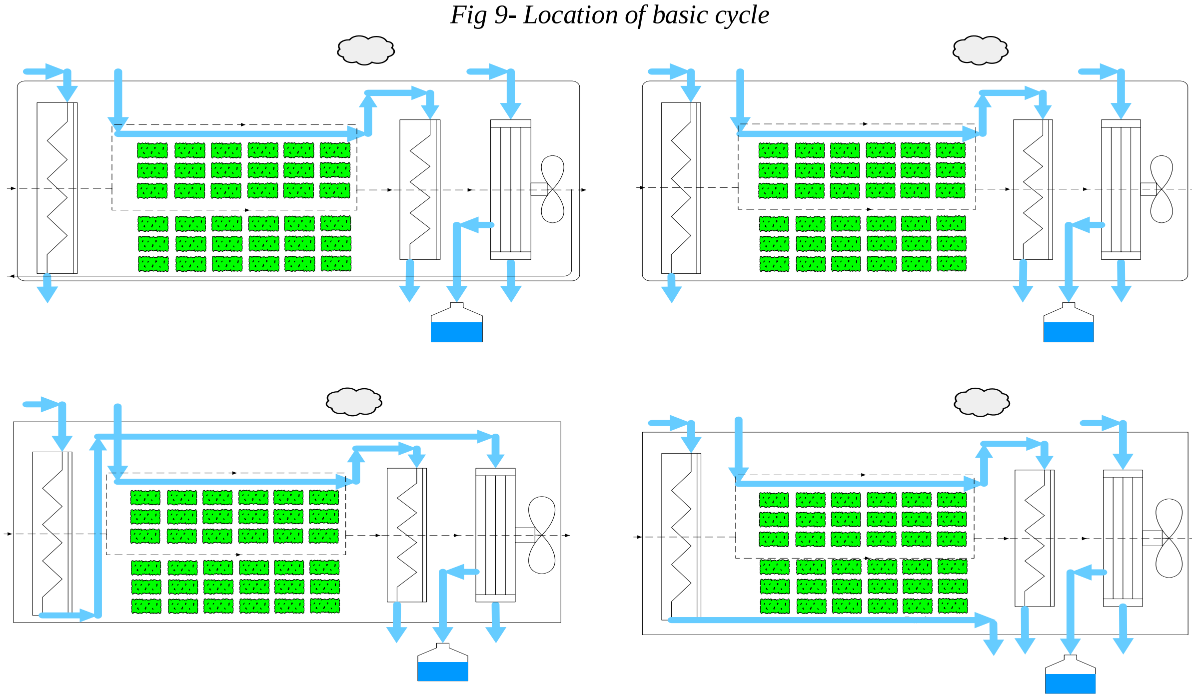


Fig 9- Location of basic cycle



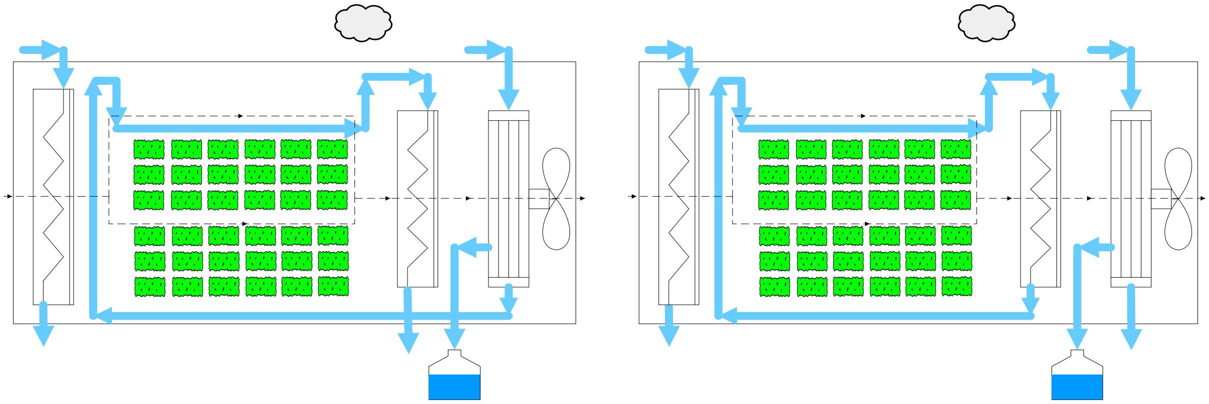


Fig 10- Location of different places in basic cycle

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