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Modeling of Seawater Greenhouse by a block diagram environment program and an equations solver program and simulations on different Moroccan locations

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ABSTRACT

In the optic of water production with pollution reduction, we treat, in this paper, humidification–dehumidification desalination process, called Seawater Greenhouse (SWGH), using an agricultural greenhouse with solar collectors as a roof, combining irrigation and desalination functions by a low-temperature distillation method. Indeed, two SWGH models were achieved, the first one on a block diagram environment program and the second one on an equations solver program. Thus, we are going to present and analyze the simulation results, provided by these models, made for different parameters and locations, in order to estimate the outlet freshwater amount depending on the site choice. As a conclusion, we will be able to draw a choice technique of the most beneficial environmental, meteorological, and geographic place of SWGH implantation, where a great producible is reachable. And thanks to this technique we have confirmed that Morocco can, technically, be very beneficial for the implantation of this desalination process, given its perfectly adapted climate with a producible exceeding 1,000 L of freshwater per day.

Keywords: Seawater; Greenhouse; Modeling; Desalination; Water; Block; Solver; Equations; Location; Morocco

1. Introduction

The availability of water resources in Morocco is affected by several factors. These resources are under increasing pressure due to population growth, the development of irrigated agriculture, urbanization, industrial growth and tourism. This could lead to a competition between the different uses of water. The availability of water resources in Morocco is also threatened by the impact of climate change, the overexploitation of aquifers, the low cost of water and the deterioration of water quality.

At the same time, the demand for water is estimated at nearly 14.3 billion m^3 in 2010, and it should reach 23.6 billion m^3 in 2030 [1].

The urban population is expected to continue to grow by 1% between 2018 and 2050 to reach 32 million habitants in 2050 against 21.9 million in 2018. Thus, the urbanization rate will go from 62.4% in 2018 to 73.6% in 2050. In addition, the National Water Plan (PNE, 2015) estimated domestic and industrial water needs at 1,437 Mm^3/y in 2010 against 2,368 Mm^3/y in 2030, which represents an increase of approximately 65%. According to a study of the Higher Planning Commission, this trend will lead to several and various issues, especially concerning the supply of drinking water and energy, pollution, and waste treatment [2].

Morocco, a country suffering from serious water stress, and for which agriculture is a key economic sector, is in a great obligation to remedy this lack of water which pragmatically represents a shortfall.

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For these reasons, this warned country turned towards the desalination of seawater, which is an inexhaustible commodity, especially for a country comprising almost 3,500 km of coastline, in both the Mediterranean and the Atlantic Ocean.

Moreover, with its warm and sunny climate and its particular interest in green technologies, it is a very good candidate for the desalination process, subject of our work. Namely, desalination by the agricultural greenhouse, or what is commonly known as Seawater Greenhouse (SWGH).

In this sense, this article presents the concentrate of our study, aiming to dissect this system in terms of technique, and also of profitability reflected by the quantity of producible.

Indeed, we began by elaborating on the mathematical modeling of our system. This was later translated to block diagram modeling and also into solver program modeling. Through these two types of computer modelling, we are able to bring out all the information concerning the behavior of our process and ensure redundancy in the simulations, whose simple correlation allows us to validate or not our model.

After the validation of our model, we made a set of simulations for different parameters. Then, we analyzed all obtained results.

This paper will focus on the impact of the implantation site choice on the producible generated by the greenhouse. As an example, this impact was measured in Morocco.

2. Mathematical modeling

The SWGH has as key components, two evaporators (humidifiers), a condenser (dehumidifier) and solar collectors as a roof. Modeling this method, is the modeling of all these components.

2.1. Evaporator #1 Formulas

We have:

$$\begin{cases} \dot{m}_1 = \dot{m}_{as} + \dot{m}_{e1} \\ \dot{m}_2 = \dot{m}_{as} + \dot{m}_{e2} \end{cases} \tag{1}$$

The amount of water evaporated through the evaporator 1 ($\dot{m}_{evap1}$):

$$\dot{m}_{evap1} = \dot{m}_{e2} - \dot{m}_{e1} = \dot{m}_2 - \dot{m}_1 \tag{2}$$

with:

$$\begin{cases} \dot{m}_{e1} = w_1 \dot{m}_{as} \\ \dot{m}_{e2} = w_2 \dot{m}_{as} \end{cases} \tag{3}$$

Thus,

$$\dot{m}_{evap1} = \dot{m}_2 - \dot{m}_1 = \dot{m}_{as}\left(w_2 - w_1\right)[4] \tag{4}$$

where:

$$w_1 = \frac{18}{29}\frac{p_{v1}}{P_{atm} - p_{v1}} \tag{5}$$

with:

$$p_{v1} = \varphi_1 p_{vs1} \tag{6}$$

$$p_{vs1} = 10^{2.7877 + (7.625T_1)/(241.6 + T_1)}[4] \tag{7}$$

Valid for $T_1 > 0°C$ with the presence of liquid water.

φ_1 measurable via psychrometer.

On the moist air diagram, the evolution of air follows an isenthalpic $h_1 = h_2$, with:

$$h_1\left(T_1, P_1, w_1\right) = C_{p,as}T_1 + w_1\left(\Delta h_{g0} + C_{p,e(v)}T_1\right) \tag{8}$$

$$h_2\left(T_2, P_2, w_2\right) = C_{p,as}T_2 + w_2\left(\Delta h_{g0} + C_{p,e(v)}T_2\right) \tag{9}$$

Δh_{g0} = 2,501.6 kJ/kg [5]

Furthermore,

$$\dot{m}_{as} = dv_1 S_1 \tag{10}$$

With:

$$d = \frac{PM}{RT} = 1.292\frac{273.15}{T_1} \tag{11}$$

T_1 expressed in Kelvin; v_1 measurable via anemometer.

2.2. Greenhouse Roof Formula

$$\dot{m}_2\left(h_3 - h_2\right) = \beta\varepsilon RT \tag{12}$$

We put for example, $\beta \cdot \varepsilon = 0.5$.

2.3. Evaporator #2 Formulas

Same approach as for evaporator 1.

With:

$$w_3 = w_2 \tag{13}$$

$$h_3 = h_4 \tag{14}$$

$$\dot{m}_{evap2} = \dot{m}_4 - \dot{m}_3 = \dot{m}_{as}\left(w_4 - w_3\right) \tag{15}$$

2.4. Condenser Formulas

Condensed water amount $\dot{m}_{\text{cond}}$:

$$\dot{m}_{\text{cond}} = \dot{m}_4 - \dot{m}_5 = \dot{m}_{\text{as}}\left(w_4 - w_5\right) \quad (16)$$

With:

$$w_5 = \frac{18}{29}\frac{p_{v5}}{P_{\text{atm}} - p_{v5}} \quad (17)$$

where

$$p_{v5} = \varphi_5 p_{\text{vs5}} \quad (18)$$

$$p_{\text{vs5}} = 10^{2.7877+(7.625T_5)/(241.6+T_5)} \quad (19)$$

Valid for $T_5 > 0°C$ with the presence of liquid water. φ_5 measurable via psychrometer.

3. System modeling via the block diagram environment and the solver program

The mathematical model previously presented has been translated to the block diagram model below.

The four blocks are respectively the subsystems modeling: Evaporator #1, the Roof, Evaporator #2 and the condenser.

Furthermore, we have spread all SWGH equations systems on the solver software file, respecting its syntax and calling, if necessary, predefined thermal functions.

The results of the simulations carried out on the Engineering Equation Solver (EES) modeling joined the results of the simulations carried out on the MATLAB/Simulink model as shown in Table 1.

4. Locations choice and meteorological data

The locations choice is based on some criteria, related to the ability of the site to offer all parameters the SWGH system needs for the water desalination process. Mainly, the place must be sunny, semi-arid to arid and obviously must be in an agricultural and coastal region.

For this study, which will concern the country of Morocco, we have chosen five different cities in five different geographical regions, but all respecting the previously cited characteristics. Namely: Nador, Kenitra, El Jadida, Agadir and Dakhla.

The following tables present all the needed meteorological data to make our simulations.

Tables 2–6 present the result of a meteorological data collection on a panel of weather databases whose references are [6] and [7]. It's worth noting that these values are statistical mean values taken over significant durations.

Table 1
Comparative table – the results of simulations carried out on the MATLAB model and on the EES model

	Produced freshwater – MATLAB/Simulink model (kg/s)	Produced freshwater – EES model (kg/s)
$T_1 = 20$	0.0149	0.0153
$T_1 = 18$	0.0175	0.0180
$T_1 = 15$	0.0206	0.0212
$T_1 = 13$	0.0222	0.0229

Data: $R = 600$ W/m^2; $\varphi_1 = 30\%$; $S_1 = 1$ m^2; $v = 3$ m/s; $\varphi_2 = 100\%$; $T = 500$ m^2

Table 2
Estimated daily mean values of meteorological parameters – Nador – Morocco

Month	Relative humidity (%)	Temperature (°C)	Wind speed (m/s)	Solar irradiation (kWh/m^2)
January	80	12.2	3.33	2.97
February	80	12.8	5.83	3.89
March	80	13.9	4.58	5.08
April	75	15.6	3.61	6.58
May	75	17.8	3.61	7.22
June	75	22.8	3.61	7.86
July	75	25	3.19	7.72
August	75	25.6	4.17	6.92
September	75	22.8	3.47	5.69
October	80	18.9	2.78	4.25
November	80	15.6	4.17	3.11
December	80	12.8	3.61	2.61
Average	77.5	17.98	3.83	5.33

Coordinates: Elevation: 19 m; Latitude: 35 10N; Longitude: 003 56W

Table 3
Estimated daily mean values of meteorological parameters – Kenitra – Morocco

Month	Relative humidity (%)	Temperature (°C)	Wind speed (m/s)	Solar irradiation (kWh/m^2)
January	81.2	12	3.06	2.94
February	79.8	13	4.17	3.89
March	77.1	14	3.33	5.22
April	75.6	16	3.75	6.44
May	74.6	18	4.31	7.31
June	74.7	21	4.17	7.64
July	74.6	23	3.89	7.58
August	76	23	3.89	6.97
September	76.2	22	3.89	5.78
October	75.9	19	3.33	4.25
November	78.2	16	3.89	3.11
December	80.5	13	3.19	2.53
Average	77.03	17.50	3.74	5.31

Coordinates: Elevation: 14 m; Latitude: 34 18N; Longitude: 006 36W

Table 4
Estimated daily mean values of meteorological parameters – El Jadida – Morocco

Month	Relative humidity (%)	Temperature (°C)	Wind speed (m/s)	Solar irradiation (kWh/m^2)
January	80.1	13	3.00	3.14
February	79.2	13.8	3.39	4.08
March	76.5	14.7	3.61	5.42
April	76.3	15.9	3.89	6.64
May	75	17.9	3.89	7.39
June	76.1	20.3	3.69	7.44
July	74.7	23.1	3.89	7.39
August	75	23.5	3.69	6.92
September	76.1	22.6	3.31	5.94
October	76.3	19.9	3.11	4.44
November	78.1	16.6	3.00	3.33
December	80.4	13.9	3.00	2.75
Average	76.98	17.93	3.46	5.41

Coordinates: Elevation: 8 m; Latitude: 33 15N; Longitude: 008 30W

Table 5
Estimated daily mean values of meteorological parameters – Agadir – Morocco

Month	Relative humidity (%)	Temperature (°C)	Wind speed (m/s)	Solar irradiation (kWh/m^2)
January	82	14	2.50	3.78
February	83	15	3.33	4.67
March	83	17	4.44	5.89
April	86	17	4.72	6.94
May	88	18	4.72	7.53
June	89	20	4.72	7.61
July	90	22	3.33	7.03
August	89	22	3.33	6.61
September	86	22	3.89	5.97
October	85	20	3.89	4.86
November	81	18	3.33	3.94
December	81	15	3.33	3.36
Average	85.25	18.33	3.80	5.68

Coordinates: Elevation: 22 m; Latitude: 30 23N; Longitude: 009 34W

5. Simulations results

Table 7 shows the results of the simulations carried out on our SWGH models, on two key months: January and August, representing respectively a cloudy, cold, wet month and a sunny, hot, arid month.

The simulations were realized for a roof area of 500 m^2 and an evaporator #1 area of 1 m^2.

In order to get a global comparison of the freshwater producible of the SWGH Fig. 3 was carried out for average values on the various cities.

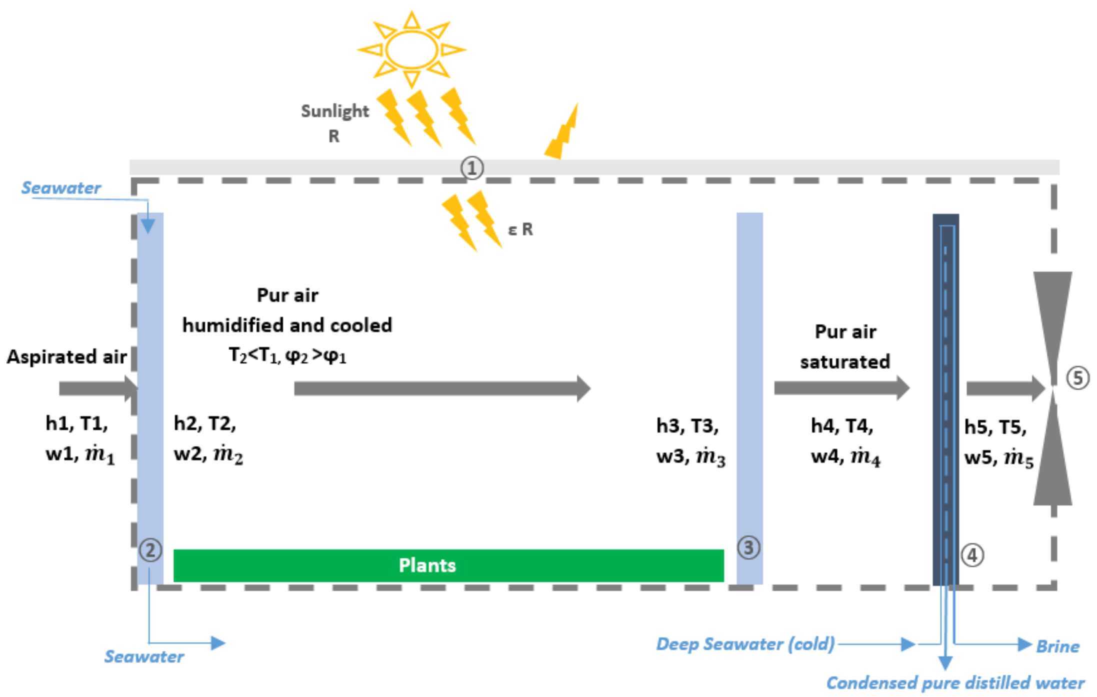
Table 7
Simulations results – estimative amount (kg/s) of SWGH generated freshwater in the different Moroccan location

	January	August
Nador	0.01998	0.04303
Kenitra	0.01948	0.04173
El Jadida	0.02082	0.04164
Agadir	0.02460	0.03721
Dakhla	0.02587	0.04185

Table 6
Estimated daily mean values of meteorological parameters – Dakhla – Morocco

Month	Relative humidity (%)	Temperature (°C)	Wind speed (m/s)	Solar irradiation (kWh/m²)
January	69.6	13.7	2.81	3.78
February	68.4	14.7	3.31	4.67
March	66.9	16.2	3.69	5.89
April	67.3	16.5	4.00	6.94
May	66.5	18.2	4.11	7.53
June	67.4	19.8	4.11	7.61
July	67.3	21.7	4.50	7.03
August	68.7	21.9	4.31	6.61
September	69.9	21.5	3.39	5.97
October	69.1	19.8	3.11	4.86
November	69.8	17.4	2.81	3.94
December	70.3	14.2	2.81	3.36
Average	68.4	18	3.58	5.69

Coordinates: Elevation: 80 m; Latitude: 30 25N; Longitude: 009 33W



(1) Greenhouse roof, (2) Evaporator n°1, (3) Evaporator n°2, (4) Condenser, (5) Fan

Fig. 1. Basic schema of Seawater Greenhouse.

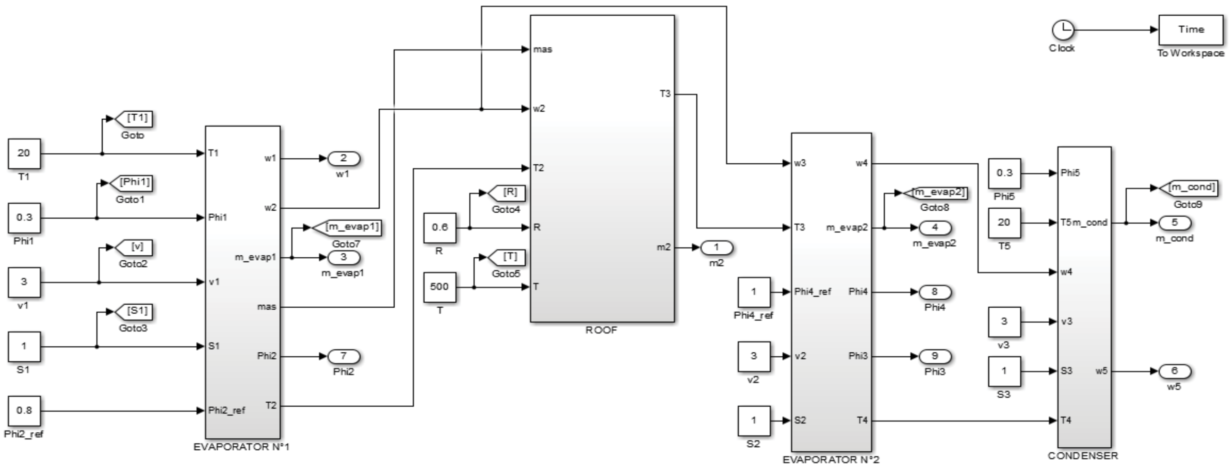


Fig. 2. Block diagram modeling of Seawater Greenhouse.

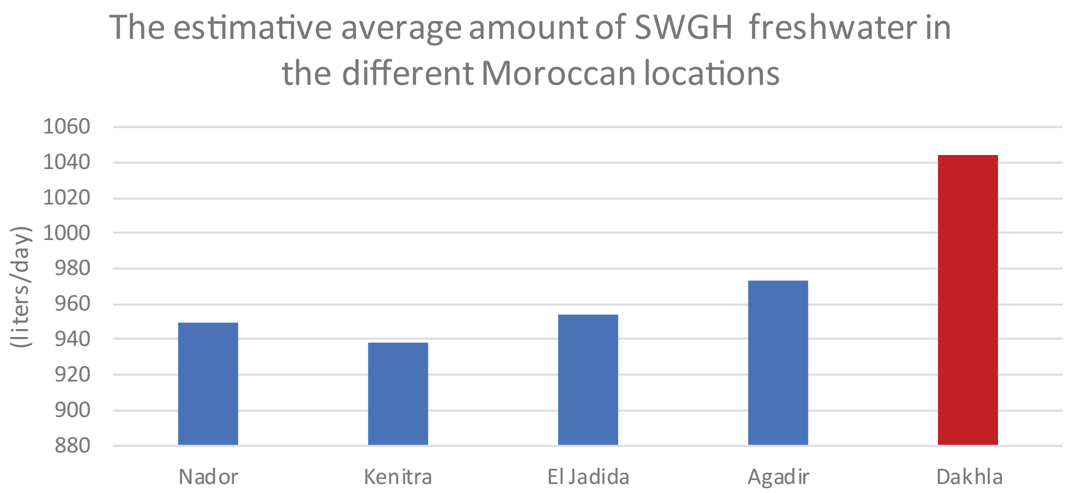


Fig. 3. The estimative average amount of SWGH freshwater in the different Moroccan locations.

6. Results analysis and location choice technique

The predefined system can produce an estimative output of freshwater greater than 1,000 L/d in the chosen cities.

In terms of annual average, the ranking by order of merit of the five cities is: Dakhla, Agadir, El Jadida, Nador and Kenitra.

The interpretation of the results values, allows us to design a location choice procedure, organized and given below:

- The location must be in a coastal and agricultural region
- The region has to be sunny and hot
- The producible is greater when the region is more arid
- Higher is the wind velocity, bigger is the amount of air entering the SWGH. Thus, greater is the generated freshwater amount.

By applying this choice procedure, we were able to achieve a production surplus going from 71 to 106 L/d. This amount exceeds the total producible of the humidification dehumidification unit based on the closed-water open-air cycle and named “Dewvaporation” which was built at Arizona State University, for a freshwater production of 45.4 L/d [8,9].

7. Conclusion

This work shows that the implementation of this desalination process in Morocco can, technically, be very beneficial, given its perfectly adapted climate.

This paper, as already mentioned, is a part of the SWGH feasibility study in this country, and it is going to provide a basis for the remaining study parts. Such as the economic evaluation, benchmarks, etc.

Once this study is completed in its entirety, this technology will be positioned precisely among other desalination technologies on the market.

Symbols and abbreviations

HD	—	Humidification–dehumidification
SWGH	—	Seawater Greenhouse
$\dot{m}_{as}$	—	Mass flow of dry air, kg/s

$\dot{m}_e$	—	Mass flow of water, kg/s
T_i	—	Temperature in the space i, °C
w	—	Absolute humidity
p_v	—	Partial pressure of vapor, Pa
P_{atm}	—	Atmospheric pressure, Pa
P_{vs}	—	Vapor saturation pressure, Pa
Φ	—	Relative humidity, %
h	—	Specific enthalpy, kJ/kg
$\Delta h_g 0$	—	Vaporization heat of water at 0°C, kJ/kg
$C_{p,e(v)}$	—	Specific heat (vapor), kJ/kg °C
$C_{p,\text{as}}$	—	Specific heat (dry air) at 100 kPa between 0°C and 50°C, kJ/kg °C
d or ϱ	—	Density of dry air, kg/m^3
v_1	—	Velocity or speed of the air entering to the greenhouse, m/s
S_1	—	Evaporator N°1 area, m^2
β	—	Percentage of radiation transmitted to the greenhouse air, %
R	—	Total solar radiation, kW/m^2
T	—	Roof area, m^2
ε	—	Transmission factor of the surface, %

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