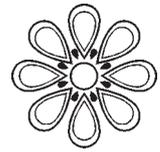




## Sensitivity analysis of the seawater greenhouse



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A SIMULATION MODEL has been developed to describe the thermal and mass balances of the air, crop, floor, inside roof, outside roof, the inlet evaporative cooling pad, the outlet humidification pad and the direct contact heat exchanger. A sensitivity analysis was used to identify those parameters which had an important influence on the model performance. The model was then used to determine the sensitivity of the rate of fresh water produced during June and December to the following parameters: efficiency of the outlet humidification pad, cooling water flow rate, seawater temperature, efficiency of the selective absorber, air flow rate through both the greenhouse and roof cavity and through the roof only.

### Model

The energy and moisture balance equations are defined per unit ground area to each node of the greenhouse: inside air (ia), crop (c), inner roof (ri), outer roof (ro), roof cavity (ci,ro), and ground (f). The ground node is subdivided into seven nodes characterising the thermal conduction in the layers of the ground. The energy fluxes between the nodes of the model are thermal radiation, latent and sensible heat.

The model (Chalabi and Bailey, 1991) is described by a set of coupled non-linear first order differential equations driven by external processes specified at the boundary nodes: outside air temperature, sky moisture content, wind speed and solar radiation. It is parameterized by a set of constants relating to the thermal, optical and geometrical properties of the seawater greenhouse.

#### Air

$$Q_{c,ia}^c + Q_{c,ia}^1 + Q_{fl,ia}^c + Q_{ia,ri}^R + Q_{ia,ri}^1 + Q_{ia,ro}^o + Q_{inf} + Q_{vent} + Q_{ia,sky}^c + Q_{cri,ro}^c + Q_{cri,ro}^1 = 0 \quad (14)$$

#### Crop

$$Q_{c,ia}^1 + Q_{c,ia}^c + Q_{fl,c}^F + Q_{c,ri}^R + Q_{c,ro}^F + Q_{sol,c}^F = 0 \quad (15)$$

#### Floor

$$Q_{fl,ia}^c + Q_{fl,p2}^k + Q_{fl,c}^T + Q_{fl,ri}^T + Q_{fl,ro}^T + Q_{sol,fl}^R = 0 \quad (16)$$

#### Inside roof

$$Q_{ia,ri}^c + Q_{ia,ri}^1 + Q_{sol,ri}^T + Q_{c,ri}^T + Q_{fl,ri}^T + Q_{ro,ri}^T + Q_{ro,ri}^F + Q_{ro,ri}^1 + Q_{ri,sky}^c + Q_{ri,sky}^1 + Q_{cri,ra}^c + Q_{cri,ro}^1 = 0 \quad (17)$$

#### Outside roof

$$Q_{ro,ri}^c + Q_{ro,ri}^F + Q_{ro,ri}^R + Q_{sol,ro}^F + Q_{ro,oa}^R + Q_{o,sky}^R + Q_{ro,sky}^1 + Q_{cri,ro}^c + Q_{cri,ro}^1 = 0 \quad (18)$$

### Results and discussion

The values of parameters not being varied during the analysis were fixed at:

Condenser area	2.31 m <sup>2</sup> /m <sup>2</sup>
Condenser heat transfer coefficient	240 W m <sup>-2</sup> K <sup>-1</sup>
Cooling water flowrate	0.1 kg m <sup>-2</sup> s <sup>-1</sup>
Wind speed	5 m s <sup>-1</sup>
Efficiency of the outlet humidification pad	100 per cent
Seawater temperature	10°C

The greenhouse had a plan area of 432m<sup>2</sup>, a length of 12m and an average height of 4m, the height of the roof cavity was 0.45m.

#### Effect of efficiency of the selective solar radiation absorber

This does have some influence on the water produced, but it is not a strong one. The reason is that water is provided both by evaporation of the seawater in the roof cavity and as transpiration from the plants. As the efficiency of the selective absorber is reduced less evaporation occurs from the roof but transpiration is increased (Figure 1).

#### Effect of cooling water flow rate through condenser

The analysis was made using condenser effectiveness for a cross flow heat exchanger with mixed flow on the air side. Figure 2 shows the influence of the condenser cooling water flow rate on fresh water production. The air flow rate in the roof cavity was 0.024kg/m<sup>2</sup> and 1.73kg/m<sup>2</sup>s in the greenhouse, the water required for transpiration by plants inside the greenhouse during June was 0.96kg/m<sup>2</sup>s.

#### Effect of the seawater temperature

The condenser cooling water temperature has a very strong influence on the amount of fresh water produced. The temperature of the seawater passing over the roof has little effect on the freshwater recovered from the roof. The condenser output decreased with the increase of cooling water temperature, at 22°C the freshwater production was 6 kg/m<sup>2</sup> a day in June (Figure 3).

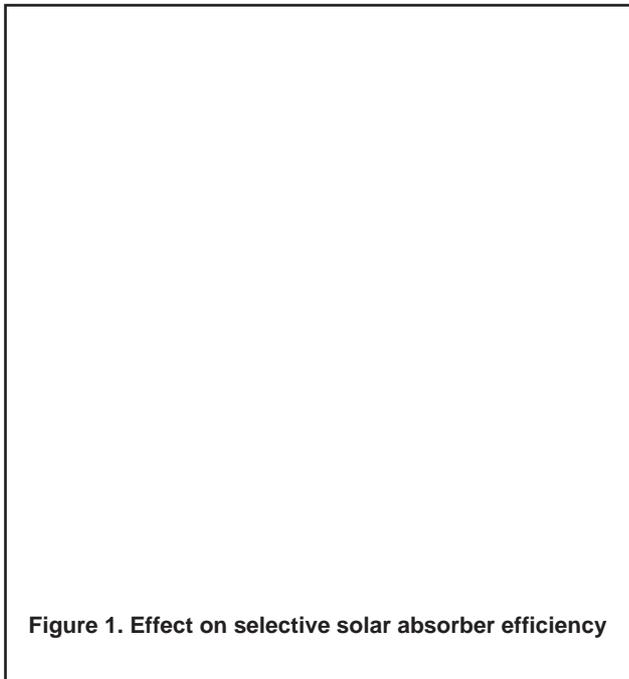


Figure 1. Effect on selective solar absorber efficiency

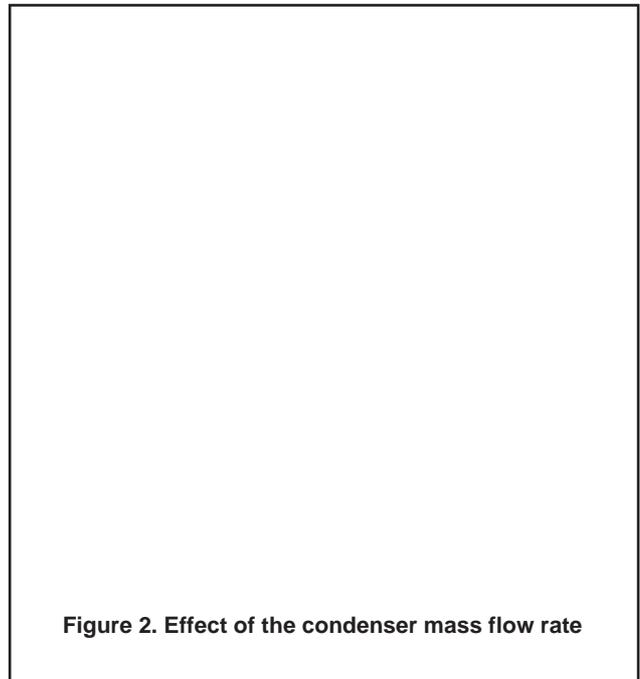


Figure 2. Effect of the condenser mass flow rate

### Effect of the efficiency of the outlet humidification pad

The efficiency of the second pad has little effect on the fresh water production (Figure 4) because the cooling water temperature of 10°C the freshwater values was very low.

### Cooling the condenser using deep seawater

#### Effect of air flow through roof cavity

When using deep seawater to cool the condenser the fresh water production increased with increasing air speed (Figure 5). With an air speed of 1.2kg/m<sup>2</sup>s in the roof, the condenser output was 1.3kg/m<sup>2</sup> day in June and 0.6kg/m<sup>2</sup> day in December. Adding the second pad increased the freshwater production by 30 per cent in June, and by 20 per cent in December.

#### Effect of air flow through both greenhouse and roof

The fresh water production was much higher compared to the fresh water produced when the air was passing through the roof only (Figure 6).

### Cooling the condenser using water at air wet bulb temperature

#### Effect of air flow through roof cavity

When using water at the air wet bulb temperature to cool the condenser, the fresh water production increased when the air speed increased (Figure 7). However, the water produced was less than the transpiration of the plants in the greenhouse the transpired water condensed in the inner surface of the greenhouse roof. In principle this water could be collected. However not ventilating the

greenhouse is unrealistic as the temperature will become too high for satisfactory plant growth. When the second pad was used, the fresh water produced increased with increasing air speed.

### Effect of air flow through both greenhouse and roof cavity

The fresh water production decreased when the air flow increased and gave 1kg/m<sup>2</sup> day in June and 0.4kg/m<sup>2</sup> day in December, at an air speed of 1.2kg/m<sup>2</sup>s; thus slowing down the air speed increases the freshwater production by raising the exit air temperature and humidity, but the higher temperature also increases transpiration. The fresh water production increased with increasing air speed and gave 7.2kg/m<sup>2</sup> day in June and 3.1kg/m<sup>2</sup> day in December, when the second pad was used.

### Conclusions

The sensitivity analysis showed that the use of the outlet humidification pad increased the fresh water production compared to using only the inlet evaporative cooling pad. The fresh water produced was higher when the air was passed through the greenhouse and roof compared to air passing through the roof only. The use of deep seawater to cool the condenser should give more fresh water production than using water at the air wet bulb temperature, and using cooling water at the wet bulb temperature will give a lower condenser outlet than using surface seawater. The mass water flowrate in the condenser should be a minimum of 0.96kg/m<sup>2</sup>s.

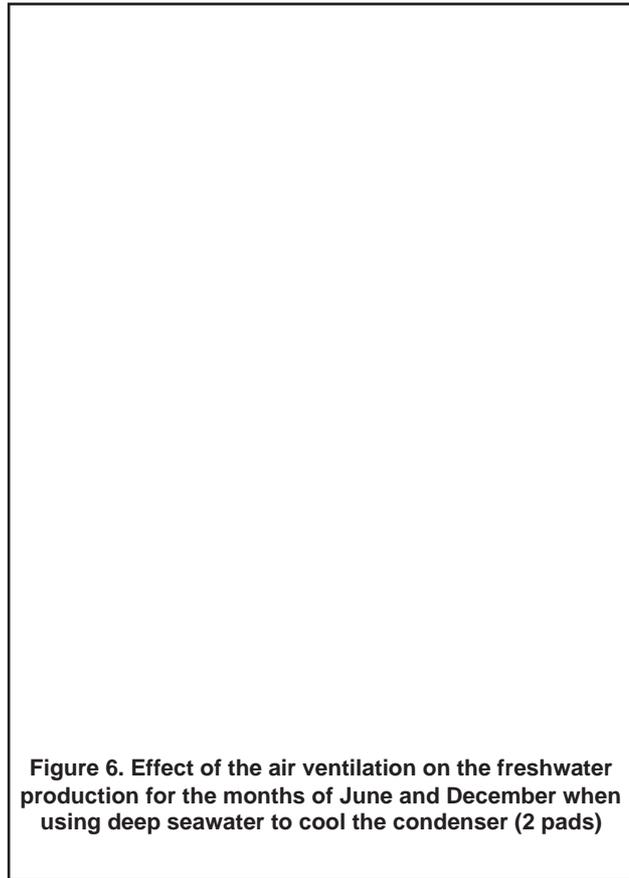
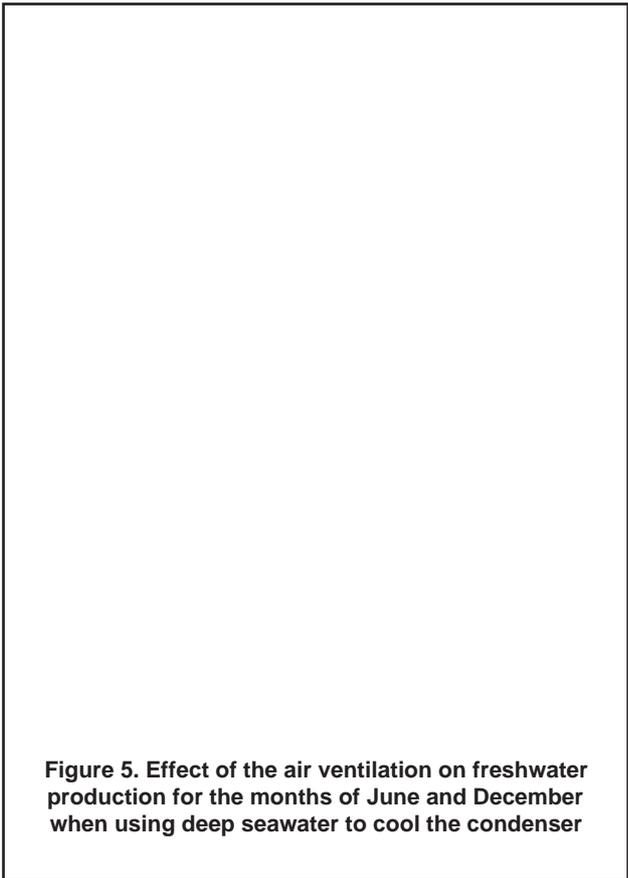
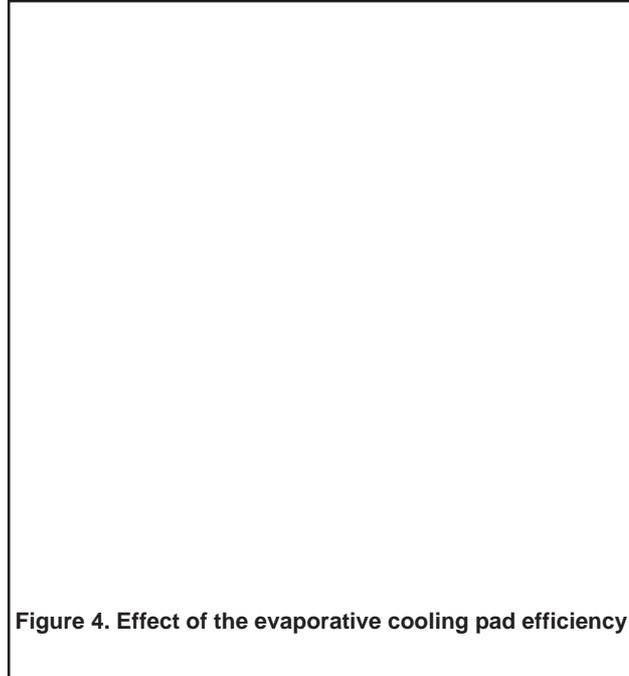
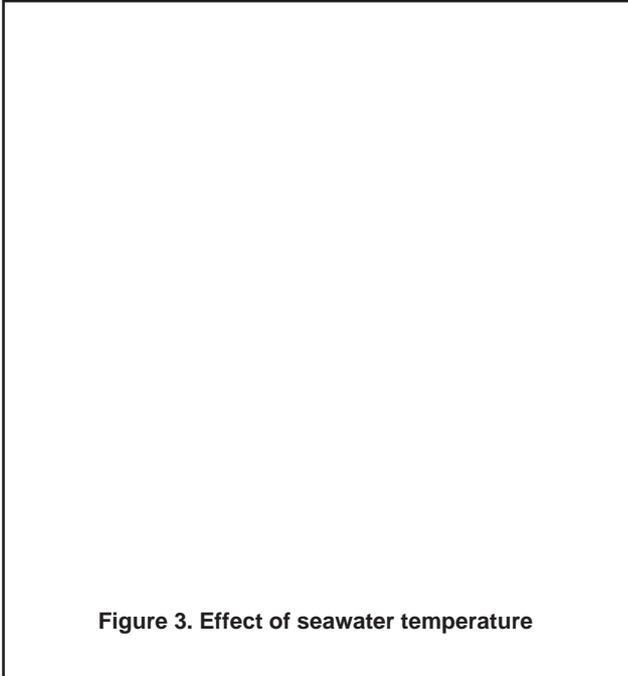
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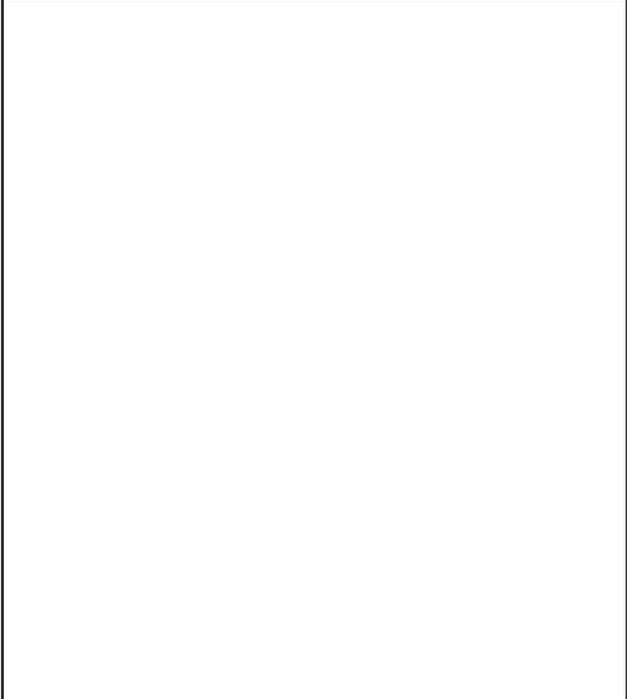
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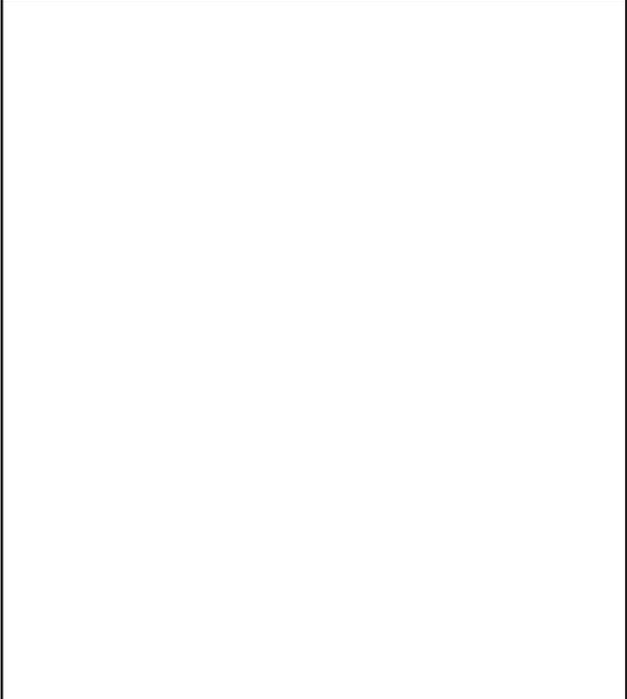
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**Figure 7. Effect of the air ventilation on the freshwater production for the months of June and December when using water at the air wet bulb temperature to cool the condenser**



**Figure 8. Effect of the air ventilation on the freshwater production for the months of June and December when using water at the air wet bulb temperature to cool the condenser (2 pads)**