Dynamic Optimization of commercial greenhouse in Middle East climatic condition using particle optimization (PSO)

Mattara Chalill Subin[1],Sai Kiran Oruganti[1] ,Amit Sinha[3]

[1]Lincoln University College Malaysia(LUCM), 47301 Petaling Jaya ,Malaysia
2Shri Mata Vaishno Devi University, India

Correspondence to: Mattara Chalill Subin (pdf.subin@lincoln.edu.my)

Abstract: Dynamic modeling is the most feasible platform to study agronomical precision level details. In the normal scenario, we are optimizing the temperature, relative humidity, and air velocity values to maintain the microclimate. However, in order to maintain a high level of precision, we shall optimize th uncertain parameters in the conditioned system. Particle swarm optimization (PSO) were used to predict the unpredicted parameters for the energy optimization process

Keywords: Greenhouse HVAC,Greenhouse climate control, Optimization , Energy prediction optimization swarm optimization (PSO)

Introduction

Dynamic modeling of the greenhouse climate is generally used for the optimization of the uncertain parameters using various dynamic equations directly related to the greenhouse indoor climate. Greenhouse operational cost in terms of commercial energy spent is the major milestone in terms of yield management. In some cases, due to the anti-seasonal nature of the greenhouse operations, energy consumption cost may reach almost 50% of the operational cost of commercial greenhouses. Therefore, it is important to predict the energy consumptions in the greenhouses. Parameter optimization-based algorithms based on energy conservation principle can provide a stronger platform in developing energy-based greenhouse optimization models (Yongato Shen et al., (2018)) [1]. In order to utilize the energy prediction in an efficient approach, the growers can implement intelligent system (Korner et al., (2008)) [2].

In the present study, the uncertain parameters for the upgraded greenhouse model for energy consumption are optimized using particle swarm optimization and genetic algorithm. The dynamic model with optimized parameters is used for energy prediction and compared with the experimental results.

2. Optimization Methodology

Indoor parameters of the greenhouse are closely related to changes in the various heat and mass transfer processes. In order to establish an accurate greenhouse model with optimal indoor parameters, it is important to study the details of this heat and mass transfer mechanism. This is a dynamic process with energy exchange between the inside and outside of the greenhouse. The energy exchange process of the upgraded greenhouse with 2mm polyethylene sheet and box type evaporative cooler is shown in Figure 1.

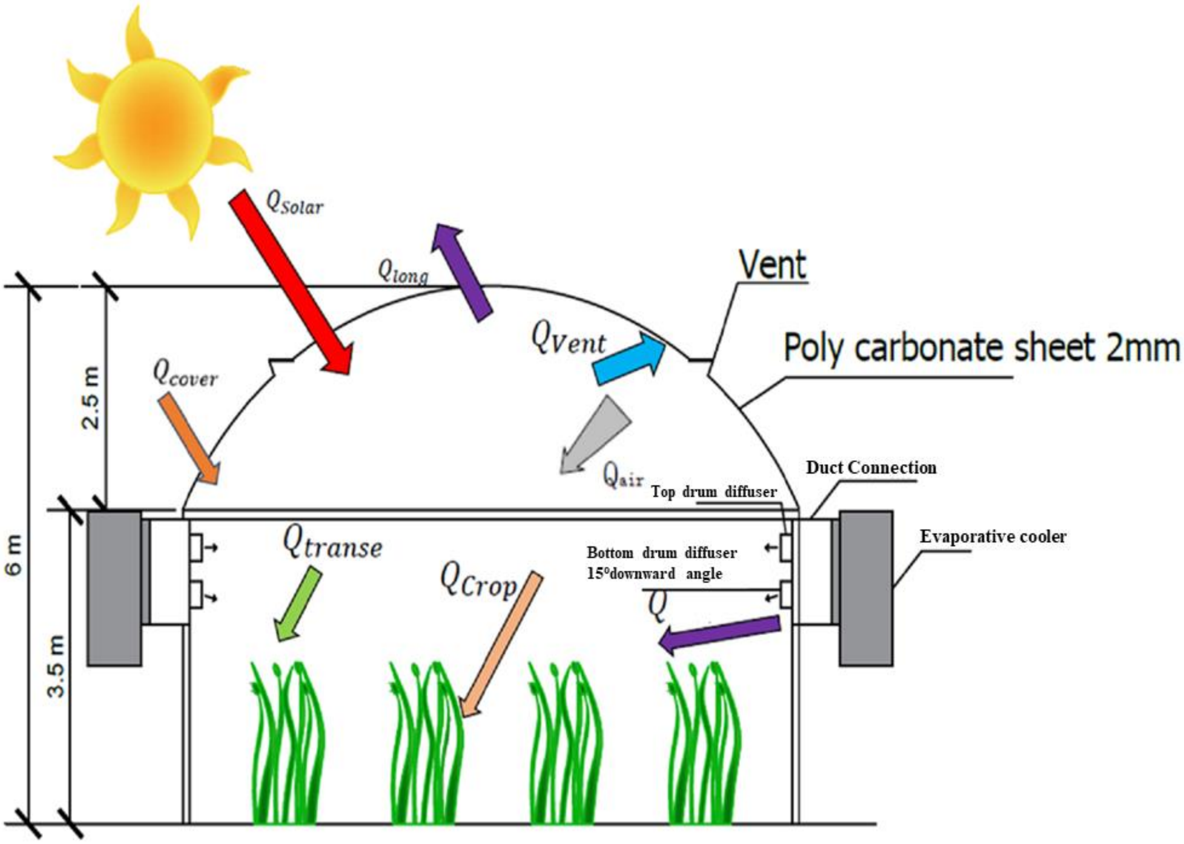


Figure 1. : Greenhouse Energy Exchange Between Indoor and Out Door

Energy exchange between the greenhouse and outside system involves various factors and Figure 1 shown above highlighted the major factors which are influencing the greenhouse indoor climatic condition in Middle East countries. Energy transferred, Q (in Watts) through the heating or cooling of the greenhouse is the sum of seven individual components as given below. List of parameters involved in the dynamic model for optimization process has been listed in the Table 1.

Table 1. : List of parameters involved in optimization

Parameter	**Description**	**Units**
$\boldsymbol{Q_{heat}}$	Net heat transfer per unit time to/from the greenhouse	Js^{-1} or W
$\boldsymbol{Q_{rad}}$	Radiative heat transfer from air at $T_{air}(t)$ to outside air at $T_{out}(t)$	Js^{-1} or W
$\boldsymbol{Q_{vent}}$	Heat energy lost from greenhouse to outside due to ventilation	Js^{-1} or W
$\boldsymbol{Q_{cover}}$	Heat exchange between the cover to outside air	Js^{-1} or W
$\boldsymbol{Q_{trans}}$	Heat exchange between plants and inside air	Js^{-1} or W
$\boldsymbol{Q_{air}}$	Heat required to raise the temperature of air	Js^{-1} or W
$\boldsymbol{Q_{crop}}$	Heat transfer from plant to greenhouse air	Js^{-1} or W
$\boldsymbol{Q_{solar}}$	Heat transfer to the greenhouse air due to solar radiation	Js^{-1} or W
$\boldsymbol{\rho_{water}}$	Density of water	$kg\ m^{-3}$
$\boldsymbol{c_{p_{water}}}$	Specific heat capacity of water	$J\ kg^{-1}C^{-1}$
$\boldsymbol{v_{water}}$	Flow rate of water in the pipeline	m^3s^{-1}
$\boldsymbol{T_{in}(t)}$	Temperature of supply water which can change with time t	℃

$\boldsymbol{T_{opt}(t)}$	Optimal temperature of return water	℃
$\boldsymbol{\epsilon}$	Emissivity of the greenhouse covering material (polyethylene or polycarbonate)	No units
$\boldsymbol{A_{cover}}$	Greenhouse cover surface area	m^2
$\boldsymbol{\sigma}$	Universal Stefan-Boltzmann constant = $5.67\ x\ 10^{-8}$	$Wm^{-2}K^{-4}$
$\boldsymbol{T_{air}(t)}$	Air temperature inside greenhouse, varies with time	℃
$\boldsymbol{T_{out}(t)}$	Outside air temperature, varies with time	℃
$\boldsymbol{X_{cover}}$	Influence coefficient of glass/ Transmittance of glass including spectral variation	Depends on cover material
$\boldsymbol{A_{gw}}$	Greenhouse ground surface area	m^2
$\boldsymbol{C_d}$	Vent discharge coefficient	No units
$\boldsymbol{g}$	Acceleration due to gravity	ms^{-2}
$\boldsymbol{A_{roof}}$	Area ratio of top windows to ground	No units
$\boldsymbol{A_{side}}$	Area ratio of side windows to ground	No units
$\boldsymbol{C_w}$	Wind pressure coefficient	No units
$\boldsymbol{V_{wind}}$	Outdoor wind speed	ms^{-1}
$\boldsymbol{\rho_{air}}$	Density of air	kgm^{-3}
$\boldsymbol{c_{P_{air}}}$	Specific heat capacity of air	$Jkg^{-1}C^{-1}$
$\boldsymbol{A_{N,side}}$	Total area of the side windows	m^2
$\boldsymbol{A_{N,roof}}$	Total area of the roof windows	m^2
$\boldsymbol{U_{vent}}$	Open percentage of top windows	No units

$\boldsymbol{X_{screen}}$	Coefficient of internal thermal curtain infiltration	No units
$\boldsymbol{LAI}$	Leaf area index (denotes surface area of leaves to ground area)	$m^2\ m^{-2}$
$\boldsymbol{\Delta H}$	Enthalpy of vaporization of water (treated as a constant)	$J\ kg^{-1}$
$\boldsymbol{\gamma}$	Psychometric constant (= 65.8)	$Pa\ K$
$\boldsymbol{VP_{can}}$	Crop canopy saturated vapor pressure	Pa
$\boldsymbol{VP_{air}}$	Saturated vapor pressure of air inside greenhouse	Pa
$\boldsymbol{L_{water}}$	Latent heat of evaporation of water from the leaf surface	$J\ kg^{-1}$
$\boldsymbol{r_b}$	Somatic resistances of leaves (Depends on canopy temperature, air temperature, concentration of air and solar radiation)	$s\ m^{-1}$
$\boldsymbol{r_s}$	Aerodynamic resistances of leaves (Depends on canopy temperature, air temperature, concentration of air and solar radiation)	$s\ m^{-1}$
$\boldsymbol{r_{s,min}}$	Minimum somatic resistances of leaves	$s\ m^{-1}$
$\boldsymbol{R_{can}}$	Solar radiation on the canopy per unit time per unit area	$J\ s^{-1}\ m^{-2}\ \ or\ Wm^{-2}$
$\boldsymbol{X_{CO_2}}$	Influence coefficient of CO_2 on stomatal opening	No units
$\boldsymbol{\rho'_{CO_2}}$	CO_2 concentration in the greenhouse	ppm
$\boldsymbol{\tau_{cover}}$	Transition coefficient of covering material	No units

$\boldsymbol{\tau_{scr}}$	Influence coefficient of shading net	No units
$\boldsymbol{U_{scr}}$	Open percentage of shading net	No units
$\boldsymbol{I_{glob}}$	Outdoor solar radiation flux (location & time dependent)	$J\ s^{-1}\ m^{-2}\ \ or\ Wm^{-2}$
$\boldsymbol{T_{can}}$	Temperature of crop canopy	℃
$\boldsymbol{H_{air}}$	Relative humidity of air	No units
$\boldsymbol{R_u}$	Universal gas constant (= 8314)	$J\ kg^{-1}\ K^{-1}$
$\boldsymbol{M_{H_2O}}$	Molecular mass of water (= 18)	$kg\ kmol^{-1}$
$\boldsymbol{v_g}$	Greenhouse volume	m^3
$\boldsymbol{\Delta t}$	Difference in time between t and $t-1$ (= 300)	s
$\boldsymbol{T_{leaf}(t)}$	Leaf temperature, varies with time	℃

$$Q_{heat} = Q_{rad} + Q_{vent} + Q_{cover} + Q_{trans} + Q_{air} + Q_{crop} + Q_{solar} \tag{1}$$

Individual components on LHS of equation (7-1)

$$Q_{heat} = \rho_{water}\, c_{p_{water}}\, v_{water}\, [T_{in}(t) - T_{opt}(t)] \tag{2}$$

Individual components on RHS of equation (7-2)

$$Q_{rad} = \epsilon A_{cover} \sigma [(T_{air}(t) + 273.15)^4 - 2(T_{out}(t) + 273.15)^4] X_{cover} \tag{3}$$

$$Q_{vent} = A_{gw} C_d \left[2g \frac{\Delta T_{air}}{T_{out}} \left(\frac{A_{roof}^2\, A_{side}^2}{A_{roof}^2 + A_{side}^2} \right) + \left(\frac{A_{roof} + A_{side}}{2} \right)^2 C_w V_{wind}^2 \right]^{\frac{1}{2}} [T_{in}(t) - T_{out}(t)]\, \rho_{air} c_{p_{air}} \tag{4}$$

$$A_{\ side} = U_{vent}\, A_{N,side} \tag{5}$$

$$A_{roof} = U_{vent}\, A_{N,roof} \tag{6}$$

$$Q_{cover} = A_{cover} X_{screen} [T_{in}(t) - T_{out}(t)]$$

(7)

$$Q_{trans} = \frac{2\rho_{air}\, c_{p_{air}}\, LAI}{\Delta H\, \gamma\, (r_b + r_s)} \quad (VP_{can} - VP_{air}) A_{gw} L_{water}$$

(8)

$$r_s = r_{s,min} \frac{R_{can}+4.3}{R_{can}+0.6} \left[1 + X_{CO_2}\left(\rho'_{CO_2} - 200\right)^2\right] \left[1 + X_P (VP_{can} - VP_{air})^2\right]$$

(9)

(X_p is neglected since the value is not significant)

$$R_{can} = 0.9\tau_{cover}[1 - (1 - \tau_{scr})U_{scr}]I_{glob}$$

(10)

$$VP_{can} = 2.229\ x\ 10^{11}\ exp\left[\frac{5385}{T_{can}+273.15}\right]$$

(11)

$$VP_{air} = \frac{H_{air}\, R_U\, (T_{air}+273.15)}{M_{H_2O}}\ x\ 10^{-3}$$

(12)

$$Q_{air} = \rho_{air} v_g c_{P_{air}} \left[\frac{T_{air}\,(t) - T_{air}(t-1)}{\Delta t}\right]$$

(13)

$$Q_{crop} = 2\ A_{gw}\ (LAI) \left[\frac{\rho_{air}\ c_{P_{air}}\ [(T_{air}(t) - T_{leaf}(t)]}{r_b}\right]$$

(14)

$$\mathrm{Q_{solar}} = 0.9\ \mathrm{A_{gw}} \tau_{\mathrm{cover}} [1 - (1 - \tau_{\mathrm{scr}}) \mathrm{U_{scr}}] \mathrm{I_{glob}}$$

(15)

3. Optimization

According to the principle of conservation of energy, physical sub-models of all the sub-models energy flow analysis have concurred. As shown in Figure 1., greenhouse's major operations have been divided into various sub-models and an energy prediction model has been established. Major physical parameters were measured with the help of field sensors and controlled accordingly. Major parameters inside the greenhouse like temperature, relative humidity, air velocity; daylight integral have been input into the model along with external disturbances. However, there are some uncertain parameters to be optimized in order to improve the efficiency of the design. Two optimization algorithms- particle swarm optimization and genetic algorithm were used. There are 7 uncertain parameters that have been optimized with the help of the above-said algorithms. Constant input parameters for the algorithm have been listed in Table 2.

Table 2. : Constant Physical Parameters Used in the Optimization Program

Sl. No.	**Symbol**	**Physical description**	**Numerical value**	**Units**
1	LAI	Leaf area index	3.21	$m^2\ m^{-2}$
2	$\mathrm{A_{cover}}$	Greenhouse cover surface area	677.19	m^2
3	σ	Stefan-Boltzmann constant	$5.67\ x\ 10^{-8}$	$Wm^{-2}K^{-4}$
4	g	Gravity acceleration.	9.8	ms^{-2}
5	$\mathrm{A_{N,side}}$	Maximum area side wall windows.	0.16	m^2s^{-2}
6	$\mathrm{A_{N,roof}}$	Maximum area top wall windows.	0.48	m^2s^{-2}
7	$\mathrm{\rho_{air}}$	Air density	1.2	kgm^{-3}
8	$\mathrm{c_{P_{air}}}$	Specific heat capacity of the air	1008	$Jkg^{-1}K^{-1}$
9	ΔH	Water evaporation latent heat constant.	$2.45\ x\ 10^6$	Jkg^{-1}
10	γ	Psychometric constant	65.8	PaK
11	$\mathrm{A_{gw}}$	Greenhouse ground surface area	272	m^2
12	$\mathrm{r_{s,min}}$	Minimum somatic resistance of the leaves	79	sm^{-1}
13	$\mathrm{L_{water}}$	Latent heat of evaporation for the leaf surface	$2.45\ x\ 10^6$	Jkg^{-1}
14	$\mathrm{M_{H_2O}}$	The molar mass of water	18	$kgkmol^{-1}$
15	$\mathrm{R_u}$	Molar gas constant	8314	$Jkmol^{-1}K^{-1}$
16	$\mathrm{\nu_g}$	Greenhouse volume	1486	m^3
17	$\mathrm{r_b}$	Aerodynamic resistance of leaves.	195	sm^{-1}
18	$\mathrm{\rho_{water}}$	Water density	1000	$kg\ m\hat{}-3$
19	$\mathrm{c_{water}}$	Specific heat capacity of water	4200	$J\ kg^{-1}C^{-1}$

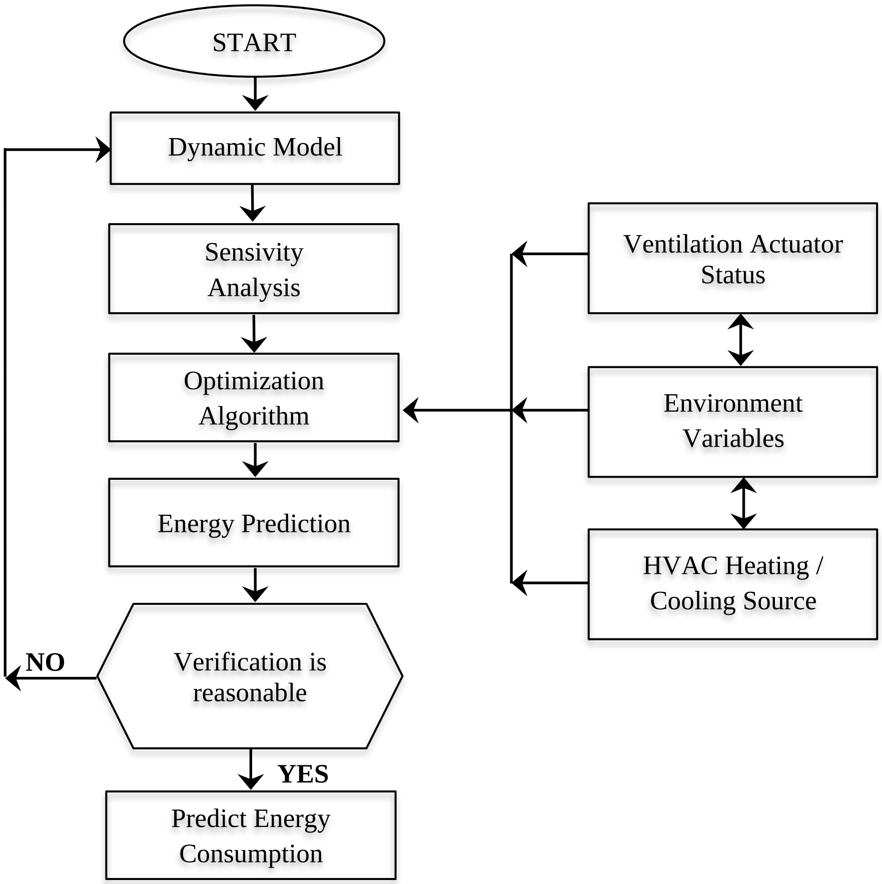


Figure 2. : Energy Prediction Model Flow Chart

4. Optimization Results

An Intel SSD processor with 10GB RAM capacity computer has been used to perform the MATLAB process for the optimization process.

PSO parameters: Max. iterations = 1400; Max. stall iterations =20; Min Neighbours Fraction = 0.25; Self Adjustment Weight = 1.49; Social Adjustment Weight = 1.49; Swarm Size = 70.

Results obtained in algorithms with respect to the predicted range have been comprehended in the Table 3.

Table 3. : Optimized Parameters Comparison with Desired Range

Parameter	Range	PSO
$\boldsymbol{\epsilon}$	$[0.5, 0.8]$	0.90
$\boldsymbol{X_{cover}}$	$[0.1, 0.9]$	0.90
$\boldsymbol{C_d}$	$[0.3, 0.5]$	0.42
$\boldsymbol{C_w}$	$[0.05, 0.2]$	0.05
$\boldsymbol{X_{screen}}$	$[0.3, 0.9]$	0.30
$\boldsymbol{\tau_{cov}}$	$[0.05, 0.2]$	0.075
$\boldsymbol{\tau_{screen}}$	$[0.3, 1.0]$	0.33

The optimum paramters obtained from both the algorithms vary slighlty. Based on the optimized parameters listed above a maximised energy prediction was carried for the summer climate in Middle East using PSO and the same was listed in the Figures 5 and 6 shown below. Maximum value of energy is in the range of 1.8×10^4 W [18kW] in PSO and prediction results but the actual power consumptions for the experimental study was 1.85×10^4W which is little higher than the optimized maximum value for the power consumption. However, the power consumption reduction in the optimized scenario is following the same pattern of the actul power consumption. Similar synchronisation results obtained for the optimization for winter climate conditons by Chen et al., (2005) [5] but the same was in the opposite cocnept such as increasing the heat inside the green house instead of cooling in summer climates. In Middle East climate, the peak summer is very crucial to control the temperature, eventhough the average energy consumption for the greenhouse observed between 14-18kW per day therefore, peak summer requires a high power consumption, therfore the total load requirement for the greenhouse energy prediction was designed into meet this challenge which is 6 to 7 times more than the actual avaerge power consumption in the winter season in the Middle East.

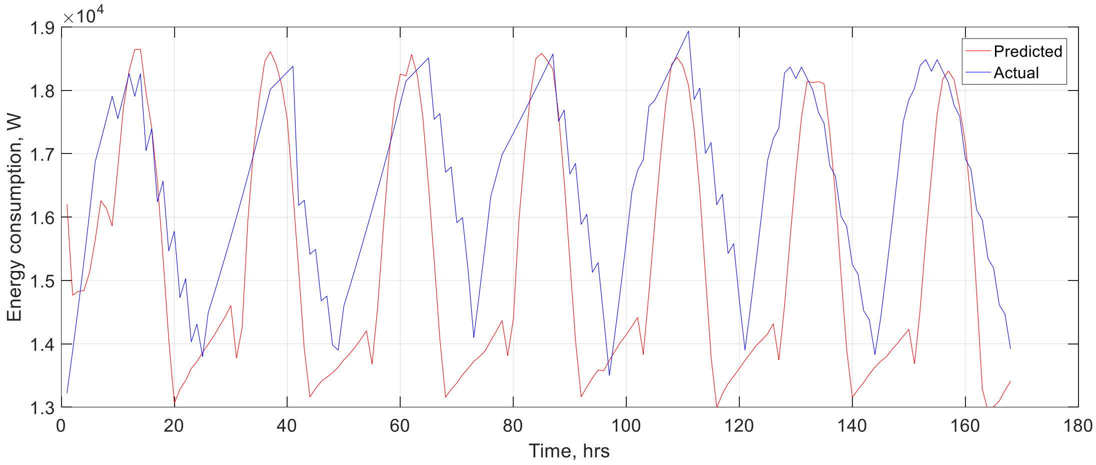
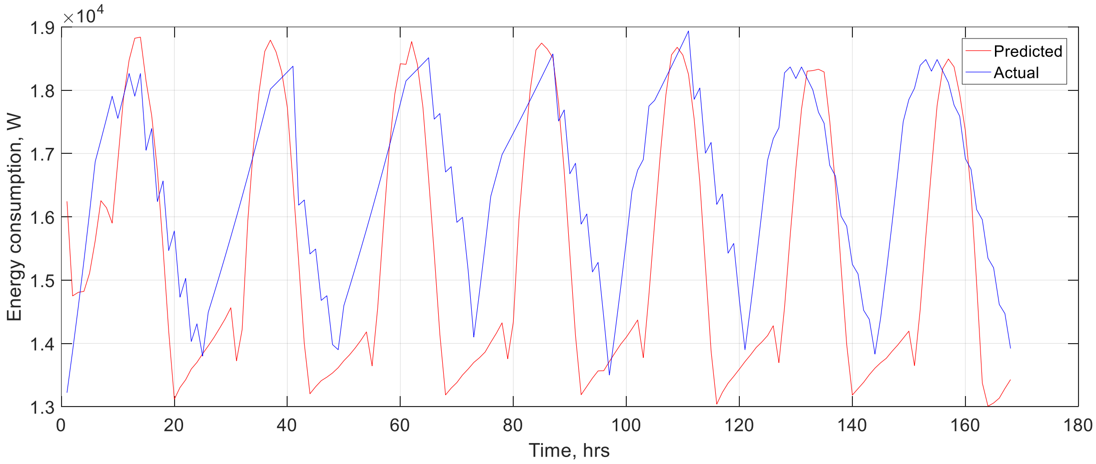


Figure 5. : Predicted Power Consumption with PSO optimization



8.Conclusion

In the present study, the greenhouse located in Middle East climate was taken as an example to predict the energy for real scenario using two major optimization algorithms. Based on the optimized seven parameters obtained, energy consumption prediction carried out in between 1st July 2025 to 7th July 2025for 7 days cycle in a summer period in United Arab Emirates. Predicted energy trend followed the same modularity as of actual energy consumption but with an optimized result. Exclusively in the present study an energy prediction model has been established in line with the real time energy production for a period of time using the PSO.Main reason for the temperature fluctuation inside the greenhouse is due to the various heat and mass transfer process between the green house and outdoor climate. Therefore, based on dynamic equation for these process with thermodynamic theory an energy prediction model is established. Based on the detailed analysis major parameters involved in the energy prediction has been identified. Further verification using GA(genetic algorithm) nd energy prediction using artificial neural network (ANN) has been scheduled as next step for the research..

References

1. Yongtao Shen ID, Ruihua Wei and Lihong Xu Energy Consumption Prediction of a Greenhouse and Optimization of Daily Average Temperature,Energies, 11, 65; doi: 10. 3390/en11010065 (2018).
2. Korner, G. and V. Straten, Decision support for dynamic greenhouse climate control strategies. Computers Electronics Agric., 60: 18–30 (2008).
3. Saemi, Behzad & Rahmani Hosseinabadi, Ali Asghar & Kardgar, Maryam & Balas, Valentina & Ebadi, Hamed. Nature Inspired Partitioning Clustering Algorithms: A Review and Analysis. 96-116. 10.1007/978-3-319-62524-9_9 (2018).
4. Vintan, Lucian. Weights Space Exploration using Genetic Algorithms for Meta-classifier in Text Document Classification. Studies in Informatics and Control (2012).
5. Chen, Q.; Sun, Z. Energy-saving control strategy for greenhouse production based on crop temperature integration. Trans. Chin. Soc. Agric. Eng., 65, 93–108 (2005).