Optimization of shape and direction of the greenhouse using gray wolf algorithm

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Abstract: Greenhouse structure is one of the most important factors in the greenhouse industry. Statistics show that the current world population will reach 8.5 billion by 2030 and 11.2 billion in 2100. Then, demand for food and water requirement will also grow. The greenhouse industry is a developing part of the agricultural sector, and the energy consumption in this industry is expected to increase energy prices which this issue is a major challenge for greenhouse owners. Greenhouses should be so designed that they have high light transmission especially in winter and at the same time satisfy the requirements of the construction cost and the safety against the loads which may be imposed upon them. In this research, the goal is to optimize the shape and direction of the greenhouse to minimize the energy required for heating. The design parameters in this work are determined for two different types of greenhouses with the target functions, with the gray wolf optimization method. Optimization of energy consumption for different models of greenhouse and different materials was performed using gray wolf algorithm. Accordingly, in each case, the best design parameters and greenhouse model were obtained and energy consumption was calculated in summer and winter. The minimum and maximum heating energy optimized in summer is related to uneven-span greenhouse with Double layer plastic in walls and ceilings (3000 W) uneven-span and uneven-span greenhouse with Double glazed glass in walls and ceilings (3600 W), respectively. The minimum and maximum heating energy optimized in winter is related to uneven-span greenhouse with Double glazed glass in walls and ceilings (1510 W) and Symmetrical greenhouse with Double layer plastic in walls and ceilings (36500 W), respectively.

Keywords: design variables, energy consumption, energy saving, particle swarm optimization (PSO) algorithm, shape and direction.

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1 Introduction

Growth in population needs higher production yield. For increasing the yields and controlling growth in all climates, greenhouse is used and it is one of the most energy demanding sector in the agricultural industry. Also, greenhouse is one of the most profitable sectors since it has a very high output which is 10 to 20 times higher than the outdoor horticulture. Energy safety and reduction of environmental pollutions are some advantages of such optimization in the agriculture sector (Younesi et al., 2021; Mostafavi and Rezaei, 2019). Greenhouses are highly sophisticated structures, which aim at providing ideal conditions for satisfactory plant growth and production throughout the year. The growth factors (light, temperature, humidity and air composition) should be delivered and maintained at optimal levels

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(Abdel-Ghany and Al-Helal, 2011; Von Elsner et al., 2000). For a greenhouse to be termed as well-designed, it must satisfy key objectives such as low construction and operation cost, efficient mechanical properties, efficient ventilation systems, low heat consumption, and allowance of high light transmittance (Çakır and Şahin, 2015; Maraveas and Tsavdaridis, 2020). The saving energy, increasing the quantity and quality of products produced compared to conventional gardening practices, has led to greenhouse cultivation as a profitable activity (Cemek et al., 2006; Cetin and Vardar, 2008; Singh et al., 2006). The design of greenhouses is confined to commercial manufacturers, and no attempt has been reported so far at its design optimization (Amir and Hasegawa, 1988; Ding et al., 2009; Dragićević, 2011). The greenhouses can be classified into two main categories based on their structural set-up: the standardized steel structures which are designed based on the national and international standards, and the low-cost greenhouses designed locally by farmers where the frames of the greenhouse are mainly wood (Geoola et al., 2009; Goggos and King, 2000; Maraveas, 2019). Structural design of greenhouse should bear safely to the wind, snow and plant loads and also allow a maximum light to the plant (Hasson, 1991; Hernández et al., 2000; Kendirli, 2006). For a successful greenhouse design, the selection of shape and orientation is paramount importance (Kılıç and Uncu, 2022; Odesola and Ezekwem, 2012). Gupta and Chandra (2002) put forward a mathematical model and they used it to investigate the effect of several measurement of energy conservation to obtain some designing features for an energy efficient greenhouse (Gupta and Tiwari, 2002).

The most recent and popular SI algorithms are gray wolf optimizer (GWO), particle swarm optimization (PSO), dragonfly algorithm (DA), and Harris Hawks optimization (HHO). GWO and PSO algorithms are two popular swarm intelligence optimization algorithms and these two algorithms have their own search mechanisms (Kılıç and Uncu, 2022; McQuiston et al., 2004; Mirjalili et al., 2014). GWO is one of the new meta-innovative algorithms for solving the optimization problems, which inspires the collective life of wolves and their hunt (Blasco et al., 2007; Mostafavi and Rezaei, 2019). In research, the GWO is benchmarked on 29 well-known test functions, and the results are verified by a comparative study with PSO, gravitational search algorithm (GSA), differential evolution (DE), evolutionary programming (EP), and evolution strategy (ES). The results show that the GWO is able to provide very competitive results compared to these well-known meta-heuristics. In order to optimize energy consumption, the choice of methods and policies for the optimum and economically use of energy is very important. In this regards, determination of the amount of the different types of energy contribution in the energy usage of each society is important given its long-term facilities. It should also use high-energy efficiency methods to reduce energy losses. Moreover, the negative effects of improper use of energy on environmental factors should be reduced. The aim of this study is to optimize energy and water consumption in greenhouses using meta-heuristic algorithm gray wolf.

2 Materials and methods

For thermal modeling of the greenhouse, received solar energy, the amount of heat lost in the greenhouse, number of used greenhouses (which are symmetrical), uneven-span and quonset are used for a more realistic comparison (Papadakis et al., 2000). Greenhouses are considered constant, and each of the shapes is divided into several sections and sections, as shown in Figure 1 (walls and ceilings). The greenhouses are initially oriented in the east-west direction as the zero-order direction. For greenhouses with arched and curved shapes, several flatbeds are used for ease of computation instead of curved shapes. The total area of the greenhouses is considered to be 100 square meters. Optimization of greenhouse dimensions is based on gray wolf algorithm and the lowest amount of cooling and heating consumption is obtained with respect to optimized dimensions. This theme is defined in three most common type and three types of materials are measured. These three types of greenhouses are very common in greenhouse agriculture.

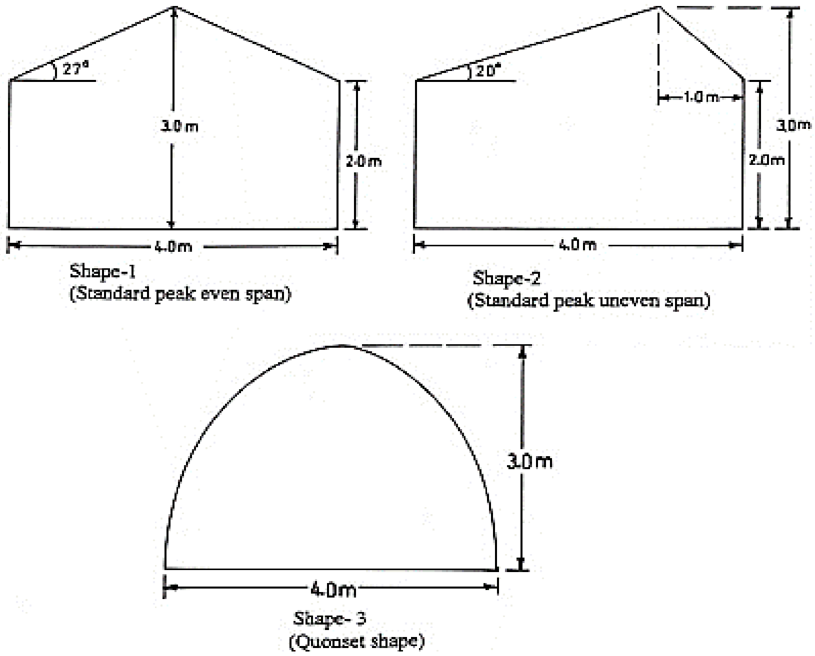

Figure 1 Dimensions of research greenhouses

2.1 Dimensional optimization parameters and its limitations

To optimize water and energy consumption, it is necessary to select the dimensions of the greenhouse correctly so that according to the type of materials selected, they have the highest heat absorption in summer and the lowest heat output in summer. Also, the desired dimensions in the problem include some limitations (Sahdev et al., 2019).

2.2 Even-span greenhouse

The first type of greenhouses for optimization are even-span greenhouses for which three design parameters are generally considered. The first design parameter is the length of the greenhouse for a fixed floor area. The second design parameter is for the overall rotation of the greenhouse and the third is the height of the greenhouse roof. These parameters are shown with parameters A, B and C in Figure 2, respectively.

Table 1 shows the limitations of even-span greenhouse optimization parameters.

Table 1 Limitations of even-span greenhouse parameters

Optimization parameter	Minimum	Maximum
A	10 meter	30 meter
B	0 radian	$\frac{\pi}{2}$ radian
C	0.5 meter	1.5 meter

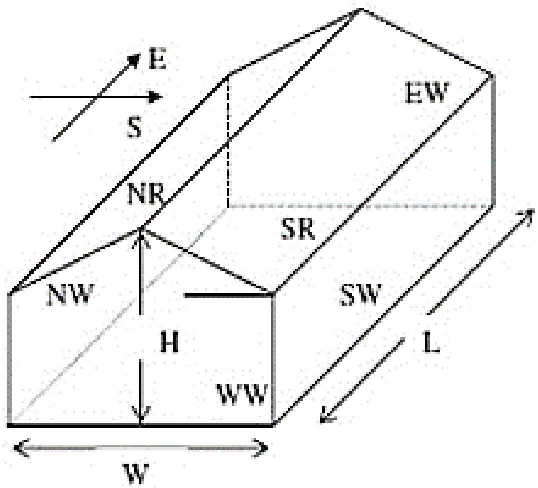

Figure 2 Even-span greenhouses

2.3 Uneven-span greenhouse

The second type of greenhouses for optimization are uneven-span greenhouses, which are generally designed for four design parameters. The first design parameter of the greenhouse is for the fixed floor area and the second parameter is for the overall rotation of the greenhouse. The third parameter is where the two plates of the greenhouse roof collide or the distance from the wall to the highest point of the greenhouse, which is measured from the north wall and multiplied by a coefficient across the width of the greenhouse. The fourth parameter of the design is the height of the greenhouse roof. Which are represented by parameters *a*, *b*, *c* and *d*, respectively (Figure 3).

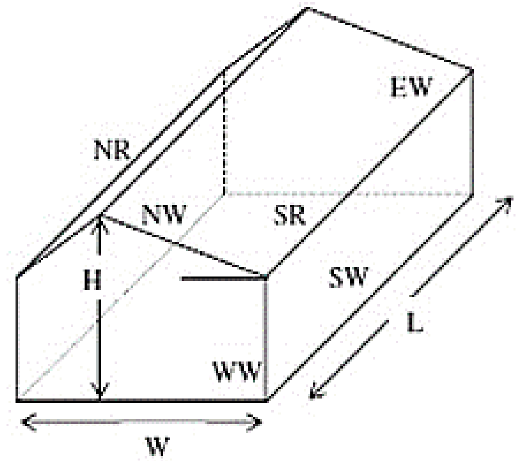

Figure 3 Uneven-span greenhouses

Table 2 shows the limitations of Uneven-span greenhouse optimization parameters.

Table 2 Limitations of Uneven-span greenhouse parameters

Optimization parameter	Minimum	Maximum
a	10 meter	30 meter
b	0 radian	$\frac{\pi}{2}$ radian
c	0.5 meter	1.5 meter
d	0.5 meter	1.5 meter

2.4 Quonset greenhouse

The third type of greenhouses for optimization are quonset greenhouses. In general, three design parameters are considered for them. The first parameter is the design of the greenhouse length for a fixed floor area, the second parameter is for the overall rotation of the greenhouse (such as a two-sided greenhouse) and the third parameter is the inter-plane angle of the roof that intersects the wall. And for the south wall and ceiling and the north wall and ceiling this angle is equal (Sethi et al., 2009). Which are shown with parameters *a*, *b*, *c*, respectively (Figure 4).

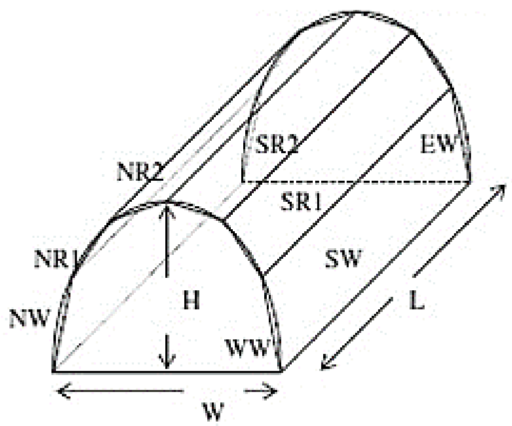

Figure 4 Quonset greenhouses

Table 3 shows the limitations of quonset greenhouse optimization parameters.

Table 3 Limitations of quonset greenhouse parameters

Optimization parameter	Minimum	Maximum
a	10 meter	30 meter
b	0 radian	$\frac{\pi}{2}$ radian
c	0 radian	$\frac{\pi}{4}$ radian

2.5 Greenhouse optimization with gray wolf algorithm

The GWO algorithm was proposed by Mirjalili et al. (2014). The social leadership and hunting technique of grey wolves were the main inspiration of this algorithm. In order to mathematical model the social hierarchy of wolves when designing GWO, the fittest solution is considered as the alpha (α) wolf. Consequently, the second and third best solutions are named beta (β) and delta (δ) wolves, respectively. The rest of the candidate solutions are assumed to be omega (ω) wolves. In the GWO algorithm the hunting (optimization) is guided by α, β, and δ. The ω wolves follow these three wolves in the search for the global optimum. In order to mathematically model the social hierarchy of wolves during the design of GWO, we consider the most appropriate solution as alpha. As a result, the second and third best solutions are called beta and delta, respectively. The remaining solutions are Omega-X. In the GWO algorithm, hunt (optimization) is guided by a, b, and d. Wolves follow three categories. For modeling of the problem, we used the gray wolf algorithm (Lupus dog) belongs to dog family. Gray wolves are considered as head predators, which means they are placed on top of the food chain. The first level is related to alpha. Alpha is more responsible for deciding on hunting, sleeping places, waking hours, etc. some cases of democratic behavior have been observed in which an alpha follows another wolf. In the rounds, the whole bunch, with their tail holding down, acknowledges alpha. The lowest grade is the Omega gray wolf. Omega plays the role of the victim. The omega wolf must always surrender to the wolves prevailing. They are the last wolves to eat. Omega members may not seem to be a significant member of the category, but it has been observed that the whole group has been struggling with domestic problems with the loss of Omega. In order to mathematically model the social hierarchy of wolves during the design of GWO, we consider the most appropriate solution as alpha (Mirjalili et al., 2014). For mathematical modeling, the blockade behavior of mathematical equations is presented in Equations 1 and 2:

$$\vec{D} = \left|\vec{C}.\overrightarrow{X_p}(t) - \vec{X}(t)\right| \quad (1)$$

$$\vec{X}(t+1) = \left|\overrightarrow{X_p}(t) - \vec{X}(t)\right| \quad (2)$$

Where t shows the current repetition, X_P is the vector of the bait position, and X is the position vector of a gray wolf. The vectors A and C are calculated as follows, Equations 3-4:

$$\vec{A} = 2\vec{a}.\overrightarrow{r_1} = \vec{a} \quad (3)$$

$$\vec{C} = 2.\overrightarrow{r_2} \quad (4)$$

A= A is a random value in the range (-2a, 2a).

C= C is a random values in the interval [2,0].

In which a is a linear vector from 2 to 0, that is reduced during the repetition period, and r_1 and r_2 are random vectors in (1,0). In order to simulate the mathematical behavior of the gray wolf hunting, we assume that alpha (the best solution), beta, and delta have the best awareness about the potential bait location. For this purpose, the Equations 5-7 were used:

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1}.\overrightarrow{X_\alpha} - \vec{X}\right|, \overrightarrow{D_\beta} = \left|\overrightarrow{C_2}.\overrightarrow{X_\beta} - \vec{X}\right|, \overrightarrow{D_\delta} = \left|\overrightarrow{C_3}.\overrightarrow{X_\delta} - \vec{X}\right| \quad (5)$$

$$\overrightarrow{X_1} = \overrightarrow{X_a} - \vec{A}_1.\left(\overrightarrow{D_a}\right).\overrightarrow{X_2} = \overrightarrow{X_\beta} - \vec{A}_2.\left(\overrightarrow{D_\beta}\right).\overrightarrow{X_2} = \overrightarrow{X_\delta} - \vec{A}_3.\left(\overrightarrow{D_a}\right) \quad (6)$$

$$\vec{X}(t+1) = \frac{\overrightarrow{X_1}+\overrightarrow{X_2}+\overrightarrow{X_3}}{3} \quad (7)$$

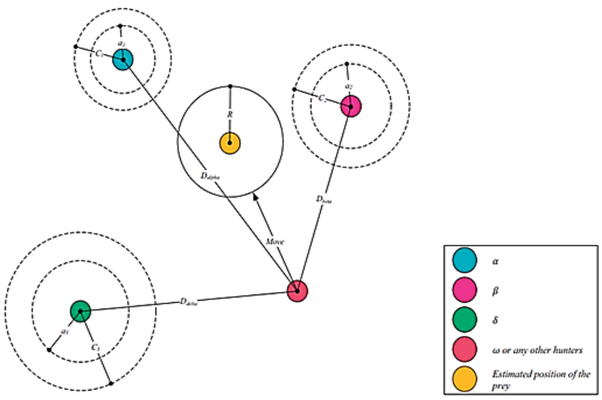

Figure 5 Updating the position when hunting in GWO

Figure 5 illustrates that how a searcher finds his position based on alpha, beta and delta in the two-dimensional search space. It can be seen that the final position in a random location in a circle is defined by the alpha, beta, and delta positions. In other words, alpha, beta, and delta estimate the position of the bait and other wolves, randomly, and update positions around the bait.

Gray wolves end the hunt by attacking the bait when the bait is left open. To reduce the amount of a for mathematical modeling of the bait. Note that the boundaries of A are reduced with a. In other words, A is a random value in the range (-2a, 2a) in which a decrease from 2 to 0 during the repetition. When the random values of A in (1,-1) the next position of a search agent can be in a location between the current position and the prey's position. The vector ⊂ C contains random values in the interval [2,0]. This component provides random weight for hunting. In order to emphasize (C> 1) or lack of emphasis (1> C). We intentionally need C to provide a random amount to emphasize the discovery during the initial repetition until the final replication. This component is very useful for optimum locks location, especially in the final replication. Moreover, the vector C is considered as the effect of barriers on approaching the bait in nature. Generally, obstacles in nature are seen on the wolf hunting path, and in fact they prevent them to approach the bait quickly and easily. In summary, the search process starts with the creation of a random population of gray wolves (the candidate solution) in the GWO algorithm. During the repetition, the alpha, beta, and delta wolves estimate the probability location of the hunt. Each wolf (the possible solution) coordinates its distance from the prey, parameter a decreases from 2 to 0, in order to emphasize exploration and exploitation (Sethi, 2009). Optimization of gray wolf was modeled in Matlab 2017 software in different greenhouses with different dimensions. The gray wolf has six inputs and system outputs include target function values and optimized parameters.

3 Results and discussion

The optimum values for heating and cooling energy in summer and winter are obtained in Table 4.

Figure 6 shows the amount of cooling energy optimized for different types of greenhouses in summer and winter. The maximum and minimum optimized cooling energy in summer is related to the symmetrical greenhouse with double glazing on the walls and ceiling and the uneven-span greenhouse with double glazing on the walls and ceiling. The highest and lowest amounts of optimized cooling energy in winter are uneven-span greenhouses with double glazing on the walls and ceiling and uneven-span greenhouses with double glazing on the walls and ceiling, respectively (Sethi and Sharma, 2007).

Table 4 The results of greenhouse modeling for consumed energy in different greenhouses

Greenhouse type	Required energy	Summer (W)	Winter (W)
Even-span greenhouse with Double glazed glass in walls and ceilings (A)	Cooling energy	34500	2100
	Heating energy	5100	31000
Even-span greenhouse with Double layer plastic in walls and ceilings (B)	Cooling energy	32500	2500
	Heating energy	3550	36500
Even-span greenhouse with one layer plastic for ceiling and Double glazed glass in walls (C)	Cooling energy	34100	3300
	Heating energy	32100	4800
Uneven-span greenhouse with Double glazed glass in walls and ceilings (D)	Cooling energy	6770	11200
	Heating energy	36000	1510
Uneven-span greenhouse with Double layer plastic in walls and ceilings(E)	Cooling energy	25600	5020
	Heating energy	3000	13200
Uneven-span greenhouse with one layer plastic for ceiling and Double glazed glass in walls (F)	Cooling energy	34000	6200
	Heating energy	3450	16200

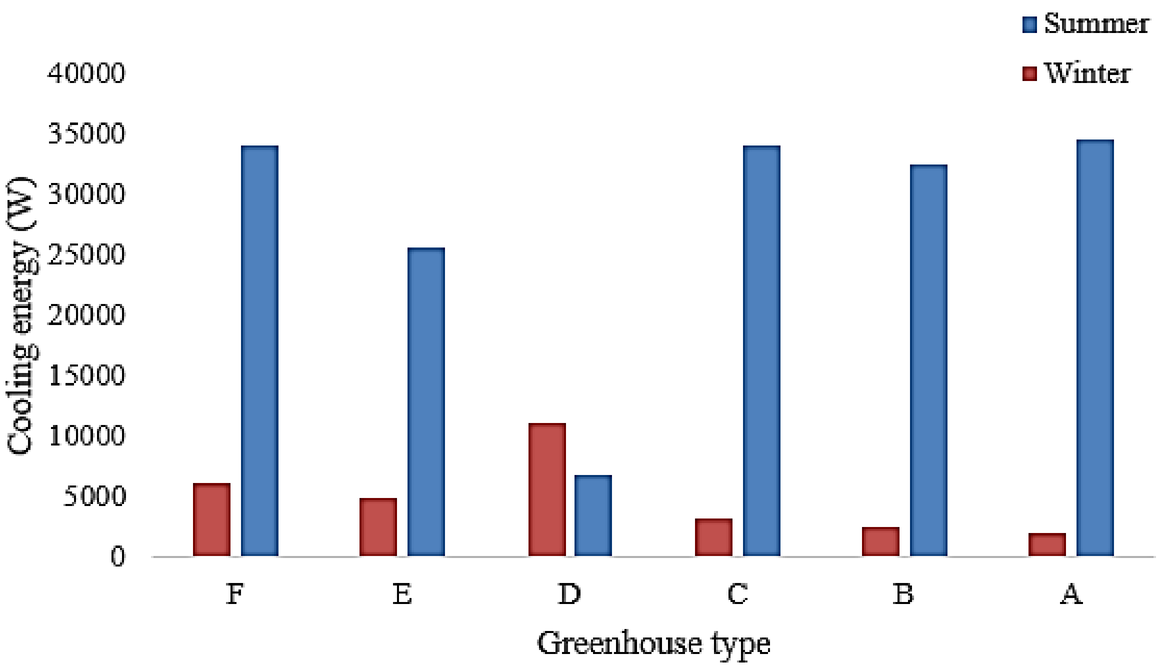

Figure 6 Optimized cooling energy for different types of greenhouses

Figure 7 shows the amount of heating energy optimized for different types of greenhouses in summer and winter. The minimum and maximum heating energy optimized in summer is related to uneven-span greenhouse with Double layer plastic in walls and ceilings uneven-span and uneven-span greenhouse with Double glazed glass in walls and ceilings, respectively. The minimum and maximum heating energy optimized in winter is related to uneven-span greenhouse with Double glazed glass in walls and ceilings and Symmetrical greenhouse with Double layer plastic in walls and ceilings, respectively (Taki et al., 2012).

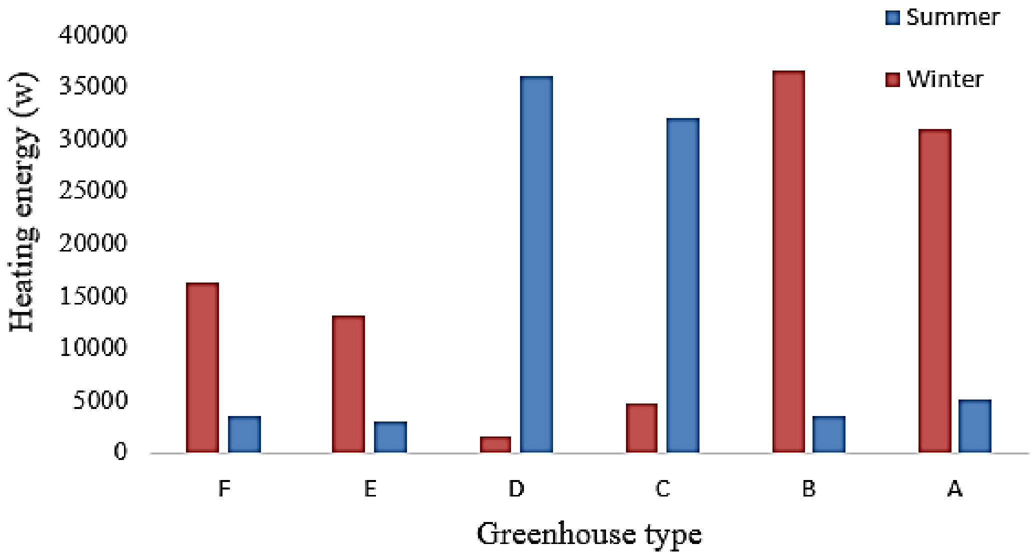

Figure 7 Optimized heating energy for different types of greenhouses

Table 5 The optimum dimensions values for different greenhouses that gained by developed model

Greenhouse type	Dimension	Summer	Winter
Even-span greenhouse with Double glazed glass in walls and ceilings	A	12	27
	B	0.55	0.28
	C	1.4	1.46
Even-span greenhouse with Double layer plastic in walls and ceilings	a	16	19
	b	0.12	1.04
	c	1.4	1.3
Even-span greenhouse with one layer plastic for ceiling and Double glazed glass in walls	a	14	26
	b	0.74	0.45
	c	1.5	1.5
Uneven-span greenhouse with Double glazed glass in walls and ceilings	a	12.08	13
	b	0.4	0
	c	0	1
	d	0.8	1.1
Uneven-span greenhouse with Double layer plastic in walls and ceilings	a	12	15
	b	0.3	0.5
	c	0	0.92
	d	0.7	1.4
Uneven-span greenhouse with one layer plastic for ceiling and Double glazed glass in walls	a	12	13
	b	0.25	0.04
	c	0	0.9
	d	0.5	1.3

In addition, the optimum dimensions values for different types of greenhouses that gained bydeveloped model are presented in Table 5.

The results show that uneven-span shape greenhouse receives the maximum and quonset shape receives the minimum solar radiation during each month of the year at all latitudes. East-west orientation is the best suited for year round greenhouse applications at all latitudes as this orientation receives greater total radiation in winter and less in summer except near the equator. Results also show that inside air temperature rise depends upon the shape of the greenhouse. The PSO algorithm is a collective search algorithm modeled on social behavior of bird categories. For symmetrical greenhouses with double-glazed glass materials, optimization were performed using two methods of gray wolf and PSO algorithm, and the amount of optimization energy were compared (Tiwari, 2003). The optimization performed by the algorithm is shown in Figure 8.

According to this form, it is revealed that the grey wolf algorithm optimization is faster and better than PSO.

Comparison of the results of two algorithms is shown in Figure 9. According to the results, the use of the gray wolf algorithm can be optimized to improve its speed it.

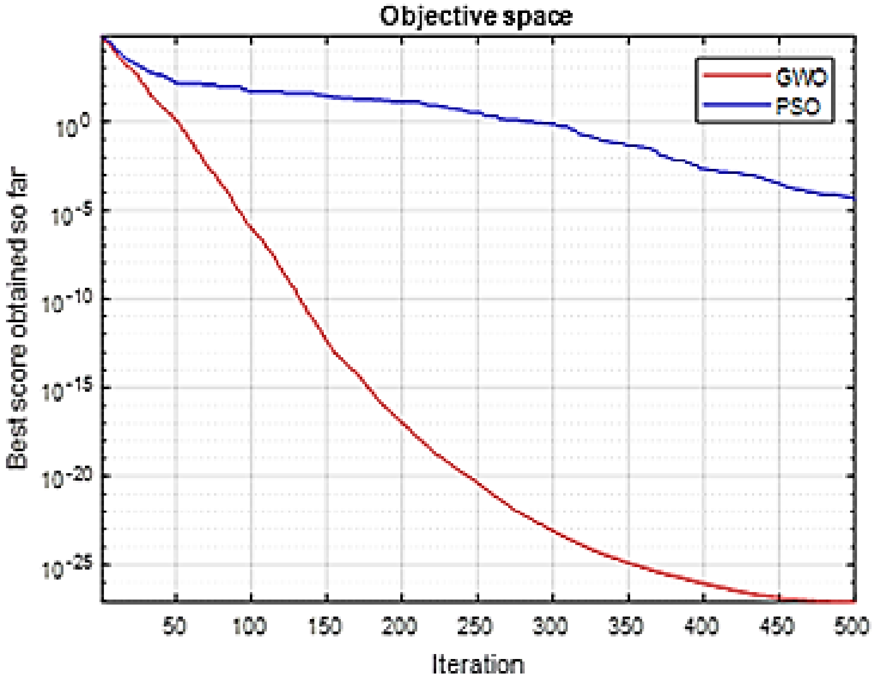

Figure 8 Comparison of optimization of GWO and PSO algorithms

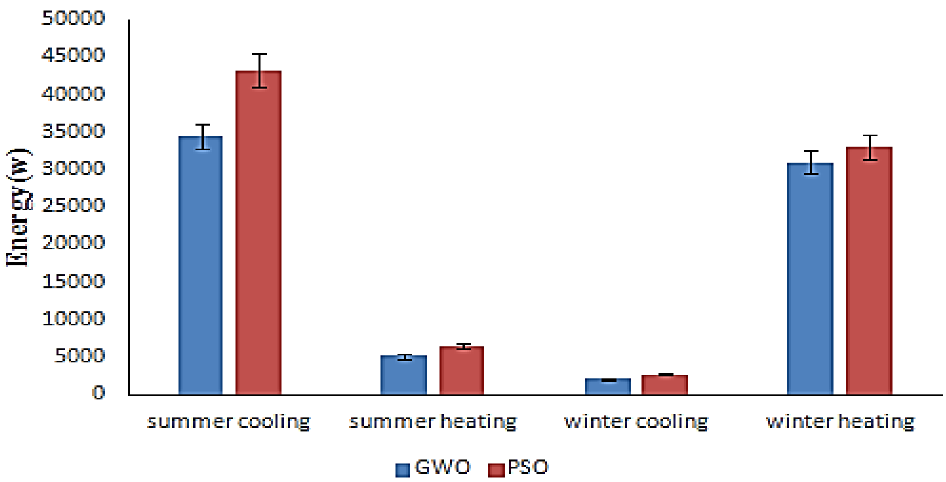

Figure 9 Comparison of the results between GWO and PSO algorithms

4 Conclusion

The water and energy crisis is one of the most fundamental issues in human societies. Agricultural products have always been the main supplier of human food needs. Nowadays, population increase and the need for attention to new and high-yielding agricultural production methods is evident. Increasing the consumers and high competition between agricultural producers has led to the development of new methods to manage greenhouse products. Saving agricultural inputs (land and water), the possibility of breeding various products without time and space limitations, increasing the quantity and quality of products produced compared to conventional gardening practices, has led to greenhouse cultivation as a profitable activity. In this research, optimization of energy consumption was carried out using an ultra-innovative gray wolf algorithm in greenhouses. For this purpose, the presented relationships for energy absorption and exhaustion in greenhouses are presented in terms of materials, angle of the sun, and so on. Then, the Greyhound algorithm was evaluated and its relationship details were evaluated. Optimization of energy consumption for different models of greenhouse and different materials was performed using gray wolf algorithm. Accordingly, in each case, the best design parameters and greenhouse model were obtained and energy consumption was calculated in summer and winter. The gray wolf algorithm was compared with the particle swarm algorithm, which indicated that the gray wolf algorithm was powerful.

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