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Solar Calculations of Modified Arch (Semi Spherical) Type Greenhouse System for Bayburt City

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Abstract**—**Greenhouses offer us suitable conditions which can be controlled easily for the growth of the plant and they are made by using a covering material that allows the sun light entering into the system. Covering material can be glass, fiber glass, plastic or another transparent element. This study investigates the solar energy usability rates and solar energy benefitting rates of a semi-spherical (modified arch) type greenhouse system according to different orientations and positions which exists under climatic conditions of Bayburt. In the concept of this study it is tried to determine the best direction and best sizes of a semi-spherical greenhouse to get best solar benefit from the sun. To achieve this aim a modeling study is made by using MATLAB. However, this modeling study is run for some determined shapes and greenhouses it can be used for different shaped greenhouses or buildings. The basic parameters are determined as greenhouse azimuth angle, the rate of size of long edge to short and seasonal solar energy gaining of greenhouse. The optimum azimuth angles of 400, 300, 250, 200, 150, 100, 50 m^2 modified arch greenhouse are 90°, 90°, 35°, 35°, 34°, 33° and 22° while their optimum k values (ratio of length to width) are 10, 10, 10, 10, 6, 4 and 4 respectively. Positioning the buildings in order to get more solar heat energy in winter and less in summer brings out energy and money savings and increases the comfort.

Keywords**—**Greenhousing, solar energy, direct radiation, renewable energy.

I. INTRODUCTION

PASSIVE heating and cooling processes can be applied in any object around the world using solar energy. It is necessary to determine primarily the utilizable solar radiation in these structures and the design of the systems where solar energy is used. Parameters such as the design of the collectors, the lighting load in the buildings, calculation of the heating power gained from the sun, the value of the solar ovens and the insolation rate of the greenhouses are established in accordance with the amount of radiation reaching the earth. The oblique rays of the winter sun and the steep-angled rays of the summer sun make the southern face of the northern hemisphere receive more solar radiation in winter and be protected easily in summer. That is why, the south-facing fronts are more valued fronts in architecture. Unfortunately, the heat energy gained from the sun is not taken into consideration in the design and construction of many buildings in our country. Especially this is completely ignored in the buildings designed by small-scale companies or constructed by individuals. As mentioned in the previous section, the south-facing fronts in such buildings are assessed separately from the other parts in quoting and solicitation planning [1].

Greenhouse is defined as a highly systematical plant growing process done in various ways in a structural building covered with different types of transparent materials such as glass or plastic to grow various plants, their seeds, seedlings and saplings, and protect or exhibit them throughout the year by controlling the factors such as heat, light, moisture and ventilation without completely or partially depending on the climate-related environmental circumstances [2]. Among the countries around the world, the USA, Japan and the Netherlands do the highest amount of greenhouse plant production. In the USA, California and Florida have the highest amount of production where 39% of the greenhouses are glass-covered. 78% of the greenhouses produce flowers. In Europe, the Netherlands is the leading greenhouse producer. Bulbed flowers are the main products. Plastic-covered greenhouses are used in countries such as Spain, France and Italy [3]. There is vast literature on solar energy and greenhouses, some of which are presented in this section. Gupta et al. demonstrated solar radiations and greenhouses in a virtual environment on AutoCAD. They used the lighting system on AutoCAD as the solar radiation. In the 3D environment they defined, they made comparisons by changing the location and design of the greenhouses [4]. Kilic and Ozturk analyzed the impact of the solar radiations on earth. They determined the angle of the solar radiations and analyzed the intensity of the solar radiation reaching the earth at different hours of the day and on different days of the year. Their study of solar energy has become an inspiration for many other forthcoming studies. The terms regarding solar angles have been accepted as in their study [1]. Pucar studied the calculation of the greenhouse wall and roof angles to receive the highest amount of solar radiation calculated the most ideal roof and wall angles, where she studied how to increase the heat effect of the solar radiation getting in through the roof and walls of the greenhouse and reflecting on the opposite wall [5]. Sethi worked on the determination of the angle and design of greenhouses that make the highest use of solar radiation. In the study, the walls of various greenhouses were studied separately in terms of their receiving solar radiation. Five types of generally accepted greenhouses were investigated in terms of the solar energy they received at every hour of the day [6].

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In this study, a numerical model was developed that estimates the dimensions and directions for receiving the highest and most direct amount of solar radiation in semi-hemispheric greenhouses suitable for the conditions in the city of Bayburt in the periods when greenhouses were actively used in the city. The estimation process was considered as an optimization problem and the numerical model was created on MATLAB accordingly.

II. The City of Bayburt

The city of Bayburt is located on the coordinates of 40°15′35″N 40°13′40″E. Bayburt has a transition climate dominated by continental climate between East Black Sea climate and East Anatolia climate. That is why, it is hot and dry in summer while is it cold and rainy in winter. However, the climate is milder than that of East Anatolia due to low altitude and the microclimate created by the system of valleys [7].

III. Solar Energy Calculations

In order to make a good use of solar energy, it is required to know the characteristics and amount of all the solar radiations in the respective area and the time period. To do that, it is necessary to determine the incidence angle of the solar radiation and the sunshine duration of the respective area in accordance with the location and earth's movement around itself and around the sun. Majority of the solar energy calculations used in this study are based on the book Solar Energy [1]

A. Real Solar Angles

The direction of the straight solar radiation reaching any point on earth can be calculated if the latitude, hour angle and the declination angle of that particular point is known. These angles are known as real solar angles. Latitude angle: It is the angle of a point on the Earth's surface from the Equatorial plane and the radius to that point. Hour angle: The hour angle of a point on the Earth's surface is the angle through which the earth would turn to bring the meridian of the point directly under the sun. Declination angle: The declination of the sun is the angle between the equator and a line drawn from the center of the Earth to the center of the sun. It is calculated as:

$$d = 23.45\, sin\left(360\frac{(n+284)}{365}\right) \quad (1)$$

B. Derived Solar Angles

Zenith Angle: It is the angle between the sun and a line that goes straight up (to the zenith). In other words, it is the angle of the solar radiation to the horizontal plane. It is calculated as:

$$\cos(z) = \cos(d).\cos(e).\cos(h) + \sin(d).\sin(e) \quad (2)$$

At the times of sunrise and sunset the solar radiations are parallel to the horizontal plane. By using these moments, the sunrise and sunset angles and day length are calculated as:

$$\cos(H) = -\frac{\sin(d).\sin(e)}{\cos(d).\cos(e)} = -\tan(d).\tan(e) \quad (3)$$

C. Inclined Plane Angles

The solar azimuth angle defines the angle of the inclined plane to a horizontal plane and projection of the normal of the plane to the horizontal plane due West. The projection of the normal of the inclined plane to the normal of the horizontal plane is cos (s) and to the horizontal plane is sin (s). Solar incidence angle (g) is the angle of the solar radiation to normal of any inclined plane, and it is calculated as:

$$\begin{aligned}\cos(g) = &\left[\cos(d).\cos(e)*\cos(h).\cos(s)\right] \\ &+\left[\cos(a).\cos(d).\sin(e).\cos(h).sin(s)\right] \\ &+\left[\sin(a).\cos(d).\sin(h).\sin(s)\right]+\left[\sin(d).\sin(e).\cos(s)\right] \\ &-\left[\cos(a).\sin(d).\cos(e).\sin(s)\right]\end{aligned} \quad (4)$$

To calculate the amount of solar energy of a plane at a given time, it is necessary to accumulate all the energy the solar radiations give from the very first moment when the solar radiation reaches the plane to the last radiation reaching the plane. For the calculation of the whole day solar radiation one should do the following. When the solar radiation is parallel to the plane, when g = 90°

$$C_1 = \sin(a).\cos(d).(\sin(s) \quad (5)$$

$$C_2 = \cos(d).\begin{bmatrix}\cos(e).\cos(s) \\ +\cos(a).\sin(e).\sin(s)\end{bmatrix} \quad (6)$$

$$C_2 = \sin(d).\begin{bmatrix}\sin(e).\cos(s) \\ -\cos(\mathrm{a}).\cos(e).\sin(s)\end{bmatrix} \quad (7)$$

$$D^2 = C_1^2 + C_2^2 - C_3^2 \quad (8)$$

This way, for $D^2>0$ the hour angles where solar radiations are parallel to plane are calculated as in (9) and (10):

$$H_{1p} = 2\, arctan\left(\frac{C_1 - D}{C_2 - C_3}\right) \quad (9)$$

$$H_{2p} = 2\, arctan\left(\frac{C_1 + D}{C_2 - C_3}\right) \quad (10)$$

The moments the solar radiation is parallel can be before the sunrise or after the sunset. That is why, if the hour angle of the solar radiation's parallel incidence to the inclined plane is bigger than sunrise hour angle in terms of absolute value, then the first incidence hour angle is at sunrise. At solar noon ($h=0^o$) the cosine of solar incidence angle (g_o) can be calculated with (11). Then, by using the algorithm in Table I, sun's first incidence and last declination angles to the inclined plane are determined.

$$\cos\left(g_0\right) = C_2 + C_3 \tag{11}$$

TABLE I
FIRST AND LAST ANGLES OF INCIDENCE OF SOLAR RADIATION TO INCLINED PLANE

		(H_1)	(H_2)
$\cos(g_o) > 0$	$D^2 > 0$	max $(H_{1p}, -H)$	min(H_{2p}, H)
$(g_o > 90^o)$	$D^2 < 0$	$-H$	H
$\cos(g_o) < 0$	$D^2 > 0$	max $(H_{2p}, -H)$	min(H_{1p}, H)
$(g_o > 90^o)$	$D^2 < 0$	No solar radiation	

How many hours solar radiation reaches the inclined plane is also another important factor. The duration of solar radiation onto the inclined plane is calculated according to:

$$For\ d > 0\ ;\ t_{eg} = \frac{2}{15} arccos\left[-\tan\left(d\right).\tan\left(e-s\right)\right] \tag{12}$$

$$For\ d < 0\ ;\qquad t_{eg} = \frac{2}{15} arccos\left[-\tan\left(e\right).\tan\left(d\right)\right] \tag{13}$$

The intensity of the solar radiation reaching inclined planes outside atmosphere changes in accordance with the angle of incidence of solar radiation and angle of inclined plane. The amount of radiation reaching the inclined planes outside the atmosphere in a day is calculated with (14):

$$Q_{oe} = \frac{12}{\pi}.I_{gs}.f.\begin{bmatrix} \frac{\pi}{180}\left(H_2 - H_1\right).\sin d \\ .\left(\sin e.\cos s - \cos e.\sin s.\cos a\right) \\ +\left(sinH_2 - sinH_1\right).cosd \\ .\left(cose.coss + sine.sins.cosa\right) \\ -\left(cosH_2 - cosH_1\right).cosd.sins.sina \end{bmatrix} \tag{14}$$

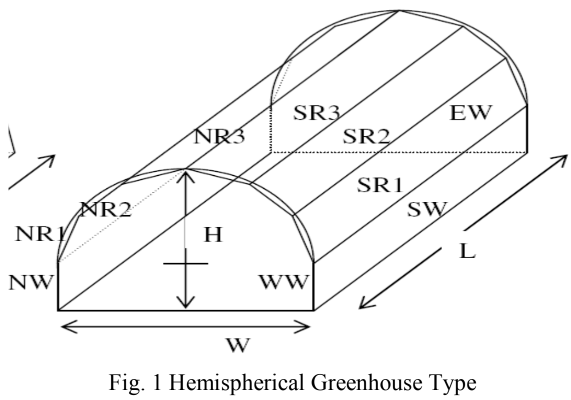

Fig. 1 Hemispherical Greenhouse Type

D. Calculations for Arch Greenhouse

A sample design is given in Fig. 1 to visually describe the greenhouse under scrutiny. As a result of this study, it is understood that there are two different seasons to use greenhouses in the city of Bayburt.

The optimum greenhouse size and direction must be determined to gather the required amount of solar radiation in these seasons (1 April - 15 June and 15 August - 10 November). For instance, for someone who plans to build a greenhouse of a certain size, the optimum size of that greenhouse, the optimum angle of direction for that size can be determined. Fig. 2 shows the schematic review of greenhouses according to different directions and angles.

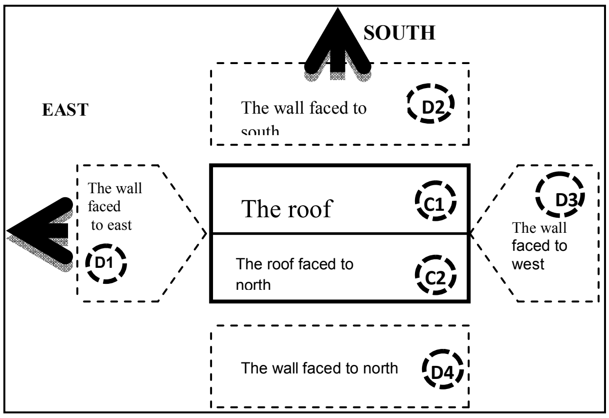

Fig. 2 Schematic review of greenhouses according to various angles

The accepted dimensions for arch greenhouses are given below. The height of the sidewalls is 2m flat. The distance between these walls and the highest point of the rooftop of the greenhouse is 1m flat too (Fig. 3). All the other necessary dimensions are calculated in accordance with the area of the roof. The length of the arch is calculated which is divided into five equal sections for solar energy calculations. The circular roof of the arch greenhouse can be analyzed as small rectangular surfaces by dividing it into small linear sections. Fig. 4 shows that the roof of the arch greenhouse is formed into five different surfaces with equal dimensions but different inclination angles by dividing it into five equal sections.

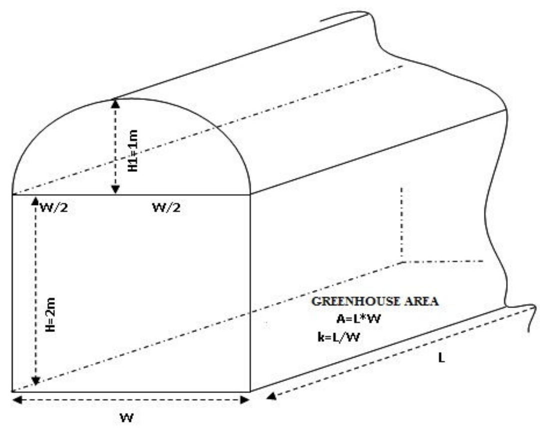

Fig. 3 Dimensions for Arch Greenhouses

IV. Assumptions

The required longitudinal solar measurement for the study in Bayburt does not exist. The study uses the direct radiation only. That is why, all of the conditions such as distributed radiation, wind, reflection, uncleanliness and datedness of the covering material, cloudiness, the shadowing impact of the greenhouse materials were regarded as the same for all greenhouses. Moreover, the maximum height inside the greenhouses of all types and sizes was regarded as limited to 3m. Since the study aims to compare different types of greenhouses to each other, these assumptions will not affect the results of the study.

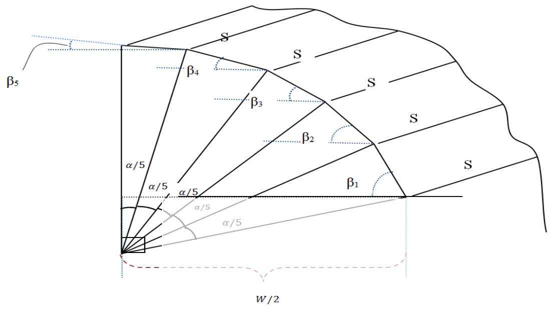

Fig. 4 Sectioning of the Circular Roof of Arch Greenhouses

V. Results

A. Arch Greenhouses with Surface Area of 400 m^2

Table II shows the dimensions of length and width and surface area of a greenhouse with a surface area of 400 m^2. Similar tables for greenhouses of various dimensions were created; however, only 400 m^2greenhouse is presented.

TABLE II
400M ^{2} Arch Greenhouse Dimension

k	L (m)	W (m)	D1, D3 (m^2)	D2, D4 (m^2)	Roof Part. (m^2)
1	20.00	20.00	53.36	40.00	40.26
2	28.28	14.14	37.75	56.57	40.53
3	34.64	11.55	30.84	69.28	40.79
4	40.00	10.00	26.72	80.00	41.05
5	44.72	8.94	23.91	89.44	41.31
6	49.00	8.166	21.84	97.98	41.57
7	52.92	7.56	20.23	105.83	41.83
8	56.57	7.07	18.93	113.14	42.08
9	60.00	6.67	17.86	120.00	42.33
10	63.25	6.33	16.95	126.49	42.59

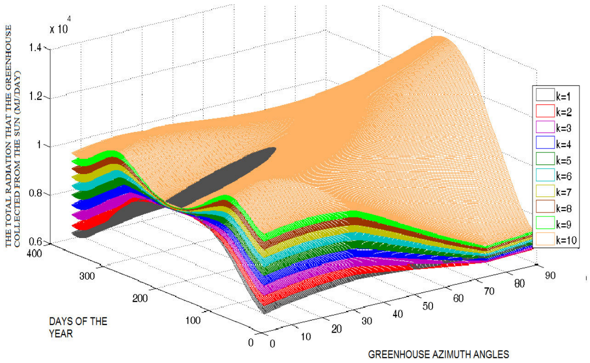

Fig. 5 Changes in Solar Radiation for 400 m^2 Arch Greenhouse

Fig. 5 shows the change in radiation levels received from the sun according to different days of the year and different azimuth angles for different k values. As seen in the figure, the higher the k value (L/W) for a 400 m^2 arch greenhouse, the higher the amount of radiation it receives. This situation changes only when it is around the middle of summer and the value of azimuth angle is lower than 40 degrees.

Fig. 6 presents the changes in total solar radiation received in the periods when the greenhouse can be used in Bayburt according to different L/W values for an arch greenhouse of 400 m^2. As seen, for a greenhouse of this type, the optimum azimuth angle is 90^o and the optimum k value is 10.

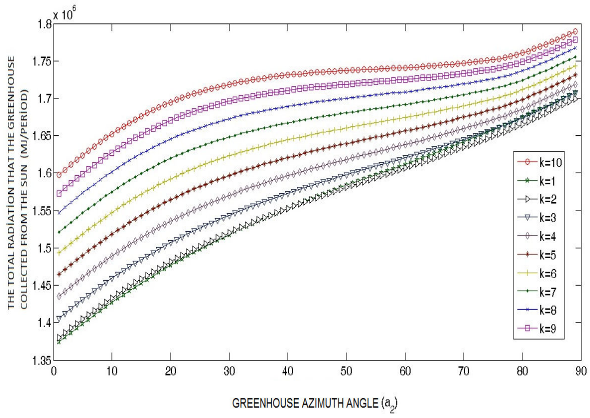

Fig. 6 Changes in Solar Radiation for 400 m^2 Arch Greenhouse

B. 300 m^2 Arch Greenhouse

Fig. 7 shows the changes in total solar radiation received in the periods when greenhouse can be used in Bayburt according to different L/W values for an arch greenhouse of 300 m^2. As seen, for a greenhouse of this type, the optimum azimuth angle is 90^o and the optimum k value is 10. The azimuth angle can also be a value between 30 and 40.

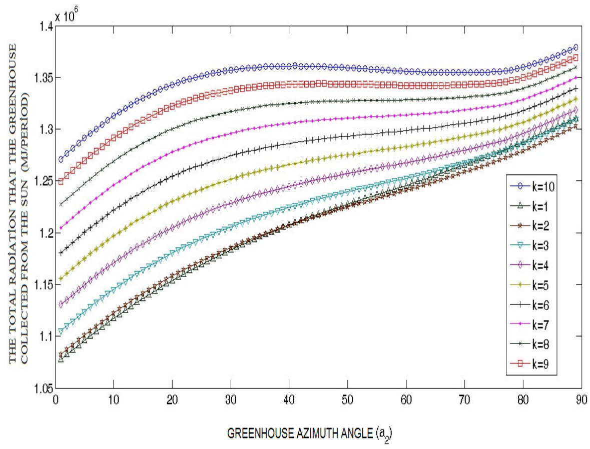

Fig. 7 Changes in Solar Radiation for 300 m^2 Arch Greenhouse

C. 250 m^2 Arch Greenhouse

Fig. 8 shows changes in radiation levels for a 250 m^2 Arch Greenhouse received from the sun according to different days of the year and different azimuth angles for different k values. As seen in the figure, the higher the k value (L/W) for a 250 m^2 arch greenhouse, the higher the amount of radiation it receives. Thus, for a greenhouse of this type, the optimum azimuth angle is 35° and the optimum k value is 10.

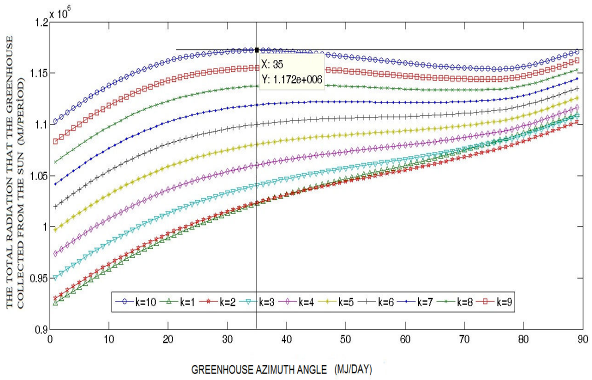

Fig. 8 Changes in Solar Radiation for 250 m^2 Arch Greenhouse

D. 200 m^2 Arch Greenhouse

Fig. 9 shows changes in total solar radiation received in the periods when greenhouse can be used according to different L/W values for an arch greenhouse of 200 m^2. As understood from the figure, the optimum k value for this greenhouse is 10. However, at this point, one should pay attention to the existing dimensions of the greenhouse and how ergonomically it has been built. It is understood that if k value is 10, then the greenhouse becomes too narrow to be used. Thus, it is considered that under these conditions the width of the greenhouse should be at least 5m and k value 8. As seen, for this type of greenhouse, the optimum azimuth angle is 35° and the optimum k value is 8.

E. 150 m^2 Arch Greenhouse

Due to the condition mentioned above, the width of this greenhouse should be at least 5 m and k value 6. Fig. 11 presents changes in total solar radiation received in the periods when greenhouse can be used according to different L/W values for an arch greenhouse of 200 m^{2}with a highest k value of 6. As can be seen, the optimum azimuth angle for this type of greenhouse is 34° and the optimum k value is 6.

F. 100 m^2 Arch Greenhouse

Fig. 11 presents changes in total solar radiation received in the periods when greenhouse can be used according to different L/W values for an arch greenhouse of 100 m^{2}with a highest k value of 4. As can be seen, the optimum azimuth angle for this type of greenhouse is 33° and the optimum k value is 4.

G. 50 m^2 Arch Greenhouse

For these conditions, it is considered that the width of the greenhouse should be at least 5m and the highest k value 5. As can be seen in Fig. 12, the optimum azimuth angle for this type of greenhouse is 22° and the optimum k value is 4.

As understood above, positioning of the greenhouses varies according to different sizes of greenhouses. This analysis is based only on the months when agricultural activities can be done. Winter season was not taken into account as farming is not possible.

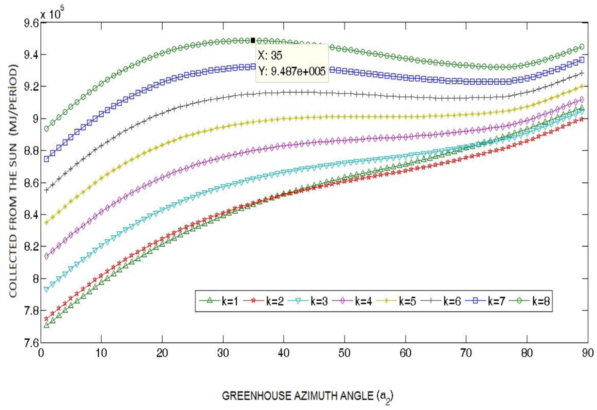

Fig. 9 Changes in Solar Radiation for 200 m^2 Arch Greenhouse

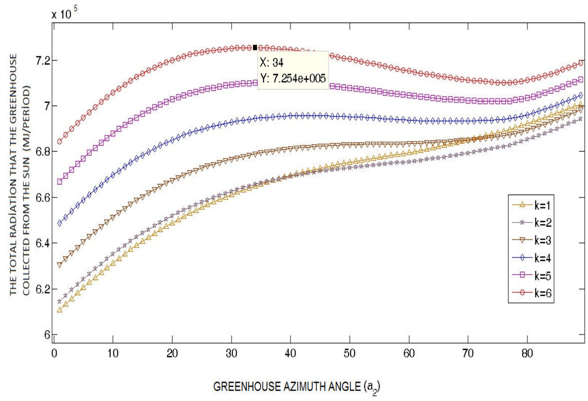

Fig. 10 Changes in Solar Radiation for 150 m^2 Arch Greenhouse

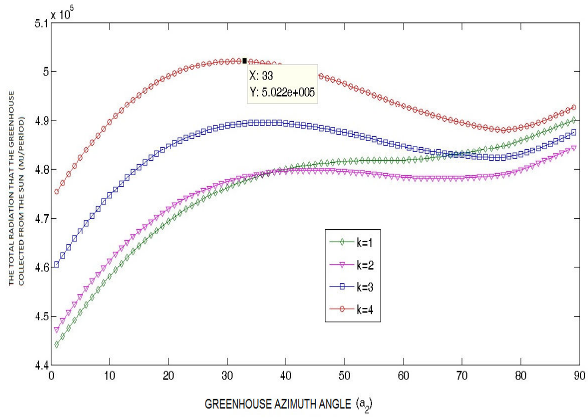

Fig. 11 Changes in Solar Radiation for 100 m^2 Arch Greenhouse

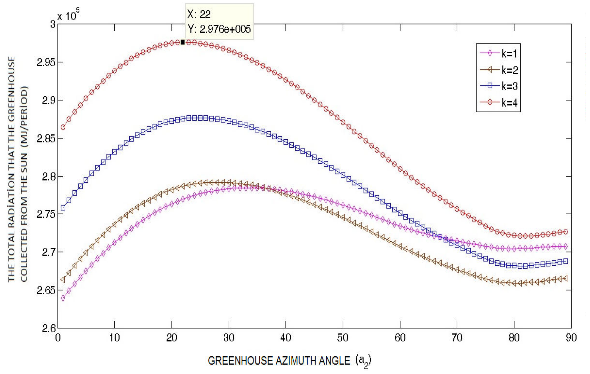

Fig. 12 Changes in Solar Radiation for 50 m^2 Arch Greenhouse

VI. Conclusion

Greenhouses are used in temperature climate regions, to make agricultural applications especially in winter. As it is known, solar radiation energy is captured and kept in greenhouses by the help of greenhouse effect. In this study, we analyzed one of the mostly used greenhouse types. Building the best and most useful greenhouses in cold climate regions mean extending the greenhouse season and increasing the productivity.

This script is applicable and suitable for other buildings such as residents and business centers in order to evaluate the solar energy incoming and provided economic benefit by saving energy. Positioning the buildings in order to get more solar heat energy in winter and less in summer brings out energy and money savings and increases the comfort.

References

[1] Kılıç A., Öztürk A. 1983. Güneş Enerjisi, Kipaş Dağıtım ve Yayıncılık (book in Turkish).
[2] MEGEP 2012, Bahçecilik ve Sera Yapım Teknikleri, (book in Turkish)
[3] Anonymous-a 2012,www.*serabirlik.com*.
[4] Gupta R., Tiwari G.N., Kumar A., Gupta Y. 2012. Calculation of total solar fraction for different orientation of greenhouse using 3D-shadow analysis in AutoCAD Energy and Buildings 47(2012) 27–34.
[5] Pucar M.D. 2001. Enhancement of ground radiation in greenhouses by reflection of direct unlight. Renewable Energy 26 (2002) 561–586
[6] Sethi V. P., 2009. On the Selection of Shape and Orientation of a Greenhouse, ermal Modeling and Experimental Validation, *Solar Energy, 83,* 1, 21-38.
[7] Anonymous-b, 2012 Ministry of Cultur and tourism /Turkey.