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Movable Thermal Screen For Saving Energy Inside The Greenhouse

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Abstract— In this work, a movable thermal screens was designed and examined for the purpose of decreasing greenhouse heating loss in Baghdad during winter nights. Three types of automatic movable thermal screens were tested to decrease the heat loss inside a greenhouse. The transparent cover area was 29.2 m^2 with 4 mm glass cover thickness. The mathematical model was formulated in four parts which are the inside air, transparent cover, soil surface, and subsoil layer. The results of the thermal curtains showed that the average temperature of the inside air during the night for the polyethylene, polypropylene, and bubble films was 8.1℃, 10.3℃, and 12.5℃ respectively and greenhouse without screens was 5.9℃. These results showed that the bubble film was more effective in a saving energy than polypropylene and polyethylene films. Good agreement was obtained between the mathematical model and the measured values (with relative root mean square errors below 5%). It was shown that the suggested different types of movable thermal curtains were powerful in decreasing heating losses, which is reached about 21.7 % compared with a greenhouse without curtains.

Keywords— Greenhouse, Thermal screen, Mathematical model, Saving energy, Movable curtains.

1. Introduction

A greenhouse is a building with a roof and walls made of translucent plastic or glass to grow the plants that need moderate climatic conditions. The technology of greenhouse is a breakthrough point in the technology of agricultural production [1]. The greenhouses designed for the purpose to provide crop control, in addition, to maintain temperature, humidity, solar radiation, and carbon dioxide rate in the Aerial climate [2]. Greenhouse micro-climate is defined by a group of average values of climatic factors, which is affected directly to the action plant growth, development, moisture contents and several other effect such as latitude, plant canopy, orientation, the area of greenhouse, shape of greenhouse and the bare area inside the greenhouse. Also, natural or forced, ventilation affect the greenhouse microclimate [3]. Ventilation is a necessary process to removes excess heat, reduce the temperature stratification, and increase carbon dioxide [4].

There are two models were used to predict the microclimate of a greenhouse which is steady state and transient methods of analysis have been used in simulating the thermal environment of a greenhouse [5, 6].

Steady state model assumes that variables do not change with time. A simple energy balance is used to calculate the heat gain by solar radiation and the heat loss to the environment by the product of the difference in temperature between the greenhouse outside and inside temperature and an overall heat exchange coefficient. The sign of the sum of the two terms mentioned above represents a heating or a cooling requirement **[7]**. This procedure is used when dealing with the greenhouse as a single component. If it treated as multiple component entities, the energy balance of several components of the greenhouse such as the interior air, roof, crop canopy, and soil have to be treated separately as reported by [6].

A steady state model was established by Mesmoudi et al. [8] to estimate the heat transfer coefficients between the greenhouse components during the night periods of the winter season. They showed that the ground of greenhouse represents the significant heat source. The heat transfer from the ground was compensated the heat losses through the walls. This phenomenon appeared clearly through the cold night days. In general, the used models are not enough acceptable and accurate due to their neglecting of the heat storage in each component and involving only a few parameters and simplicity.

Transient models are more accurate for simulating the thermal condition and climate of greenhouse and its response on a small timescale. They require a proper representation of the heat transfer and mass transfer action between the different active and radiant components. The coefficients of heat transfer, as well as the mass transfer, are depending on the system variables [9].

During night time in winter months, a thermal curtain/screen is dropping outside or inside a greenhouse cover to conserve the energy inside it. The curtain is rolled up during daytime to let the radiation of solar to come inside a greenhouse for the thermal heating. The internal curtain adds stagnant air layers between the glazing and the interior of the greenhouse. Therefore, it provides an effective, simple and low-cost way to decrease the heat loss in the night. Aluminized polyester film is favorite choice as a thermal curtains/screens out of many other materials due to its capability to save from 23 % to 60 % of the cost of heat energy the greenhouse at several places without spending any exterior energy [10]. Thermal curtain/screens can be coupled with geothermal sources which can increase the temperature of inside air about 8 – 12℃ [11] and rock bed storage which can economize about 90 % from heat needed [12]. Some disadvantages are poor mechanical reliability, incomplete sealing after closure, and condensation damage to curtains and plants **[6, 15]**.

The aim of this study is to construct movable thermal screen inside the greenhouse to less heat losses in a specified condition. This method is too efficient to decrease the heating load which is required in winter nights. The effect of screen on the temperature inside the greenhouse will be presented. Design and construction movable thermal screen inside the greenhouse. Thermal screens were accomplished with a control system. Different types of thermal screen were tested experimentally.

2. Mathematical Modeling

The algebraic equations of the mathematical model that related to the greenhouse climate have been developed. The greenhouse under study is modelled in **Figure 1** showing all the heat exchange between the greenhouse and a surrounding.

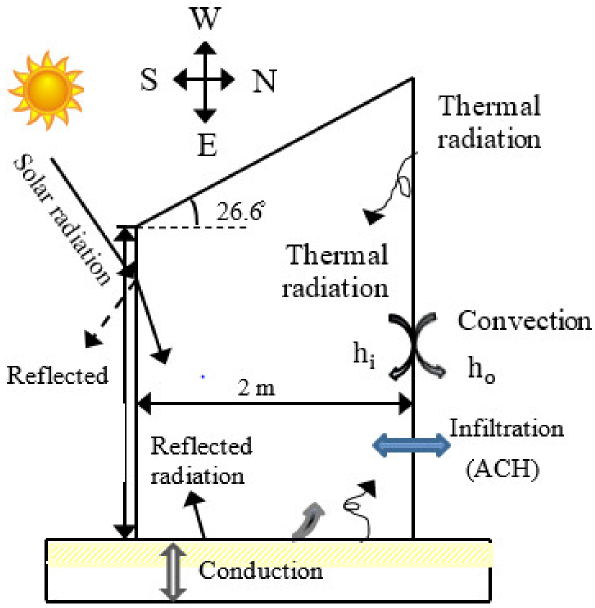

Figure 1: The greenhouse model and its heat exchange with the surroundings [6].

The greenhouse equations were formulated in four parts which are the inside air, transparent cover, soil surface, and subsoil layer. These elements are represented by four of differential equations with first order which have been obtained, in this work, from the energy balance for each element.

The first equation of the energy balance is derived per m^2 for the greenhouse cover as in equation (1).

$$\rho_s\, cp_s\, z_0\, \frac{dT_s}{dt} = q_{ss} - q_{co,s-i} - q_{k,s-1} + q_{r,s}^{net} \quad (1)$$

The energy balance equation derived for the interior air per m^2 of soil surface area as in equation (2).

$$\rho_i cp_i H \frac{dT_i}{dt} = q_{co,s-i} - q_{\inf} - q_{co,i-c} \quad (2)$$

The third equation of the energy balance is derived per m^2 for the greenhouse soil surface as in equation (3).

$$\rho_s cp_s z_o \frac{dT_s}{dt} = q_{ss} - q_{co,s-i} - q_{k,s-1} + q_{r,s}^{net} \quad (3)$$

The general equation of heat transfer by conduction from a soil surface at the depth 1 cm to the subsoil is show in the following equation according to [5, 14] as in equation (4).

$$q_k = \frac{2k_s(T_s - T_{s1})}{z_o + z_1} \quad (4)$$

The last energy balance equation which is derived per m^2 for the subsoil layer at depth 50 cm below the ground, according to [15, 5] as in equation (5).

$$\rho_s cp_s z_1 \frac{dT_{s1}}{dt} = \frac{2K_s(T_s - T_{s1})}{z_o + z_1} - \frac{2K_s(T_{s1} - T_{s2})}{z_1 + z_2} \quad 1 < z \le 50 \quad (5)$$

The heat transfer equation by convection between the greenhouse elements According to reference [5] are shown in equations (6), (7), and (8).

$$q_{co.c-a} = h_{co.c-a}\,(T_c - T_a) \quad (6)$$

$$q_{co.i-c} = h_{co.i-c}\,(T_i - T_c) \quad (7)$$

$$q_{co.s-i} = h_{co.s-i}\,(T_s - T_i) \quad (8)$$

According to references [5, 15] the net radiative of the heat flux on the cover of the greenhouse is shown in equations (9), and (10).

$$q_{r,c}^{net} = \frac{-\epsilon_c \sigma T_c^4 S_c + \alpha_{ct}\epsilon_{sky}\sigma T_{sky}^4 S_c\ \alpha_{ct}\epsilon_s \sigma T_s^4 S_s}{S_s}) \quad (9)$$

$$q_{r,s}^{net} = \frac{-\epsilon_s \sigma T_s^4 S_s + \alpha_{ct}\epsilon_c \sigma T_c^4 S_c}{S_s}) \quad (10)$$

The temperature of the sky is suggested by reference [16] and is used in the above equation as in equation (11).

$$T_{sky} = 0.552\, T_a^{1.5} \qquad T_a \text{ in } (K^{\circ}) \quad (11)$$

Some workers neglect the solar radiation that reflected from a soil surface [17, 18]. While this effect does not neglect in this work for more accurate in the analysis. The heat balance is given in equation (12) and the soil surface reflectivity is the last term of this equation [5]. This effect may be reached about 12 % of a solar radiation that absorbed by the greenhouse cover.

$$q_{sc} = \alpha_c\, I\,(1 + \tau_c\,(1 - \alpha_s)) \quad (12)$$

$$q_{ss} = \alpha_s\, \tau_c\, I \quad (13)$$

The greenhouse infiltration can be written as follows [19] in equation (14).

$$q_{inf} = \rho_a\, cp_a\, N\, H \frac{(T_i - T_a)}{3600} \quad (14)$$

The relations that indicated to calculate the coefficient of the heat transfer between the greenhouse surfaces is written according to reference [20] as in equation (15), (16), and (17).

$$h_{co.c-a} = 0.9 + 6.76\,(V_w)^{0.49} \quad (15)$$

Where $Tc > Ta$ and $V_w \leq 6.3\ ms^{-1}$

$$h_{co.i-c} = 1.95\,(Tc - Ti)^{0.3} \quad (16)$$

$$h_{co.s-i} = 1.52\,(Ts - Ti)^{0.33} \quad (17)$$

The energy balance equations of the greenhouse with double layer will be the same of the equations of the energy balance for a greenhouse with single cover except equation (1) will be changed because additional resistance will be added to the cover and which can be written in equation (18).

$$\rho_c cp_c b \frac{dT_c}{dt} = q_{sc} + q_{r,c}^{net} + q_{co,i-c} - q_{co,c-a} + q_{k,i-c} \quad (18)$$

The heat conduction of the double cover of the greenhouse per m^2 is written in equation (19).

$$q_{k.i-c.} = \frac{T_i - T_c}{\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}} \quad (19)$$

Computation of the greenhouse microclimate is based on quasi steady state energy balance equations. The MATLAB with standard solver by ode45function was applied to solve the four differential equations (1), (2), (3), (5). The computation of these four equations helps to calculate the interior air temperature, soil temperature, cover temperature, and temperature of soil sub layers. A measured ambient temperature, wind speed, and solar radiation and are used as input data for this program.

3. Experimental work

One of the objectives of the research was constructed a controlled movable thermal screen inside a greenhouse to reduce the heat losses. The experiments were implemented from November 2016 to March 2017. The greenhouse was without crops, with (latitude 33.3°N, longitude 44.4°E, and altitude 32 m above the sea level). A greenhouse was built y by reference [5], and it was made from a wooden structures built with poles that measuring 100 mm × 50 mm. A transparent cover from ordinary single glass with 4 mm thickness. The space areas were recessed to fix the layers of the glass which were held in the place with the strips of wood materials measuring about 100 mm × 50 mm. To prevent the greenhouse from the ventilation of air with the surroundings and the leakage of water the edge of the glass was covered with silicon material. The back height of the greenhouse is 3m which is the veritable height of the greenhouse in traditional greenhouses. And the other opposite height is 2 m, width 2m, floor surface area 7.6 m², and the slope of the roof became 26.6°. The greenhouse under study is shown in **Figure 2**.

Figure 2: Show the wooden truss of the greenhouse.

Three different thermal screens were used inside the greenhouse as follows. A single polyethylene sheet (PE, UV) 300μm thick, single polypropylene sheet (PP) plastic film and single (PE) air bubble film (solawrap). The air gap between the blind and greenhouse cover (glass) was 10 cm. The movable thermal screens were located inside the greenhouse to protect it from outside conditions. The movable thermal screen was designed and constructed handle, it was consisted of a rotary pipe of aluminum material with a diameter 2 cm. These rotary pipes were placed horizontally along each side of the greenhouse wall at the top edge of the wall, it was connected from one end with DC motor (12V, 14RPM) and the other end was fixed with pillow block bearing with an inside diameter 2cm. The top edge of the blind was connected to the rotary pipe and during the operation the blind twist around the pipe, the bottom edge of the blind was fastened with heavy load a bar with 0.5 inch width, also the blind move on a vertical railroad in order to give the blind stability during the operation. The opening of the thermal curtains during about 8 A.M. and closing about 5 P.M. According to the control electric circuit, that contains the following: eight pieces of relay each one with 10 A, 24 V, four pieces of gear box electric motor (12 VDC, 14 RPM and 5.202 kg.cm Rated Torque), eight pieces of the Electronic Digital PNP Transistor, pic model 16f84a, thermistors LM35, some different resistances, led lights, wires, power supply, switch on/off. These components were connected together to build the thermal screen controller, which the transistors used to drive the relays and the pic were contained specific programming in order to give a command signal for operating the motors. The sensor LM 35 was used for sensing the air temperature inside the greenhouse, the led lights mention of rising and dropping the blinds, also consist of temperature controller to setting the temperature. **Figure 3** show the internal blind and its controller.

The greenhouse temperature measured by using 16 Thermistors. Sixteen Thermistors sensors model LM35 were used to measure inside temperature. It is having the measuring range between -55 to 150℃ (the error is 0.25℃ at the temperature of the room). The temperatures were recorded every minute during the day. The Thermistors are put in a pipe to avoid direct sun array. The test begins usually around 6:00 A.M. The thermal screen was opened between 8:00-10:00 A.M. and closed about 5:00 P.M. by thermal screens controller.

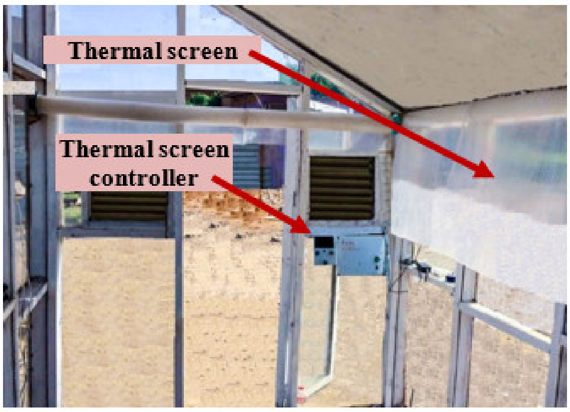

Figure 3: Show the internal blind and controller of blinds

4. Results and Discussion

In this work the effect of using three types of blinds for unheated greenhouse to decrease the heat losses. To understand the conditions of greenhouse without any type of blinds Figure 4 shows the hourly variation of the measured value of the greenhouse micro-climate for a typical winter day. Inside air temperatures, soil surface temperature at 1 cm depth and subsoil temperature 50 cm depth varies with solar radiation intensity and reach maximum values about two hours after solar noon. The maximum inside air and soil surface temperatures in a clear sky day in January were 35.8 ̊C and 34.7 ̊C at 2 P.M, respectively. The minimum temperatures were 2.3 ºC and 7.6 ºC at 6 A.M. Clearly, the air temperature is higher than soil temperature during the day while, during the night the soil surface temperature is higher than the inside air temperature. This is due to heat storage of the absorbed solar radiation by the soil during the day. The average difference between the air and soil surface temperatures in this typical day for the period from 6 P.M. to 6 A.M. was about 5℃. This is a significant factor in reducing the heating cost during the night.

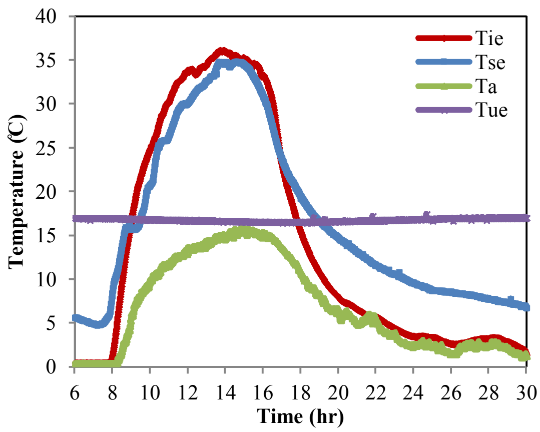

Figure 4: Variations of greenhouse temperatures vs. time (glass cover only) of day on 28-01-2017 for clear sky.

An indication of the effectiveness of solar radiation intensity on greenhouse micro-climate is apparent in Figure 5. For partly cloudy day in January. The maximum inside air and soil surface temperatures were 22℃ and 18.7℃, respectively. The minimum temperatures were 1.1℃ and 6.7℃, respectively. The temperature of the soil 50 cm depth below the ground measured also, for the same clear and partly cloudy of previous days and it was ranged between 16.4℃ to 17.3℃ for both days. This is because the soil surface affected by the solar radiation energy, convection with the inside air, and conduction with the soil surface and the effect of these parameters will be decreased whenever soil depth increased. This results was agreed with the results that found by reference [5, 21].

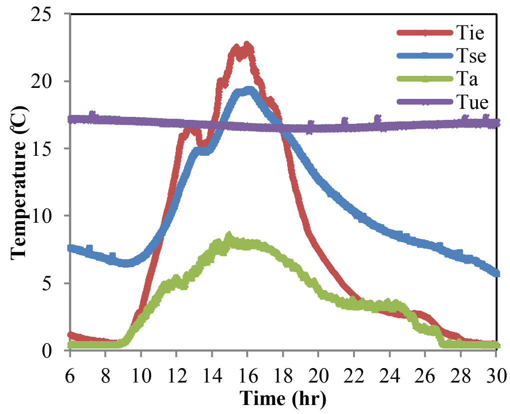

Figure 5: Variations of greenhouse temperatures vs. time (glass cover only) of day on 27-01-2017 for partly cloudy sky.

A comparisons between theoretical and experimental results for greenhouse inside air temperature for clear sky is shown in Figure 6.

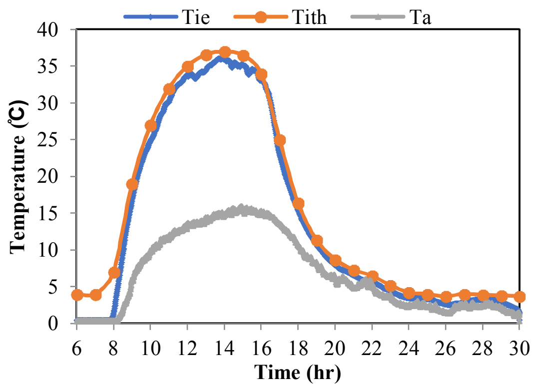

Figure 6: Comparison between theoretical and experimental of inside air temperatures vs. time of day on 28-01-2017 for clear sky.

Observation shows that the theoretical model performance is quite good during the whole day. A comparisons between theoretical and experimental results for greenhouse inside soil temperatures for clear sky is shown in Figure 7.

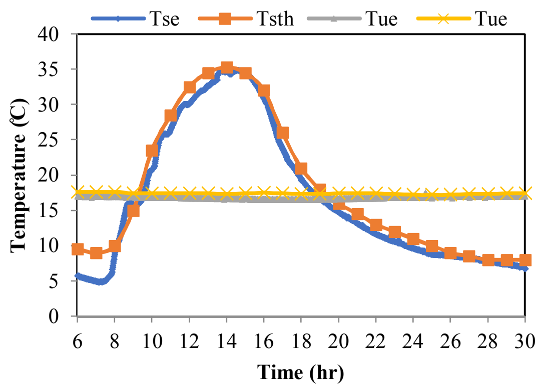

Figure 7: Comparison between theoretical and experimental of inside soil temperatures vs. time of day on 28-01-2017 for clear sky.

The theoretical model performance is quite good during the whole day, the slight difference was caused by the integrated values for solar radiation, which was used as an input to the program. Also the theoretical value is higher than the experimental value during the period from 6 to 8 A.M. and that's due to the initial boundary conditions of the Matlab program. The measured values for unheated greenhouse with double cover are collected. The using of the double cover during the daytime reduces the incoming daytime energy at the soil surface more than a single cover. So, for this work, the thermal curtains are used during the night to get high solar energy stored in the soil during the daytime and in same time decreasing the heat losses during the night. Also, to protect the curtains properties from the solar radiation. The variation of temperature difference between the inside air temperature and ambient temperatures for different types of curtains from 5 P.M. to 6 A.M. is shown in Figure 8.

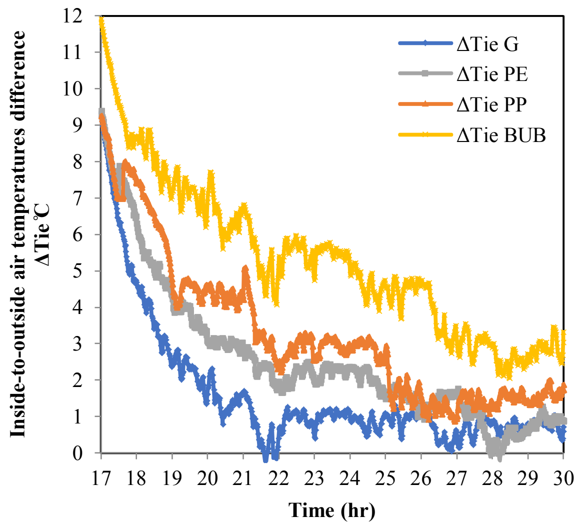

Figure 8: Variations of difference ΔTie vs. time for clear skies for the days (28-31)-01-2017

At the time about 5 P.M. that inside temperatures starting to decrease lower than 20℃ and that's lead to pulled down the thermal screens automatically by the thermal screen controller. From table 1. the effect of the thermal screens appeared clearly.

Table 1: Show curtains effect on inside air and soil surface temperatures

Cover type	Tie	Tse	Ta	Tie-Ta	Tse-Ta
Glass cover	5.9	10.5	4.80	1.1	5.7
Glass cover + PE blind	8.1	12.3	4.78	3.32	7.52
Glass cover + PP blind	10.3	14.2	4.91	5.39	9.29
Glass cover + BUB blind	12.5	16.6	4.96	7.54	11.64

5. Conclusions

The following conclusions can be deduced from the present study:

1- The soil surface and the interior air temperatures of a greenhouse reach their maximum value approximately two hours after the noon in the winter season, while a minimum value occurs before sunrise

2- The results of the thermal curtains showed that the average temperature of the inside air during the night for the PE, PP, and bubble films was 8.1℃, 10.3℃, and 12.5℃ respectively and greenhouse without screens was 5.9℃. This result showed that the bubble film was more effective in a saving energy than PP and PE films.

3- The results of the thermal curtains showed that the average temperature of the soil surface during the night for the PE, PP, and bubble films was 12.3℃, 14.2℃, and 16.6℃ respectively and greenhouse without screens was 10.5℃.

4- The thermal screens decrease of the heat load that used to heat a greenhouse during the night, and the results showed that a bubble film can save of heat load operation about 3:39 hours, while PP and PE can save about 1:45, 1:04 hour, respectively.

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Nomenclature

A	Area m^2
b	Cover thickness m
c_p	Specific heat of air J/kg. K
H	Back height of greenhouse m
h	Enthalpy of air/ Convection heat transfer coefficient KJ/kg, $W/m^2.K$
I	Incident solar radiation
k	Thermal conductivity W/m. K
N	Number of air change per hour
q_{co}	Convection heat transfer rate W/m^2

q_{inf}	Infiltration heat transfer rate W/m^2
q_r	Radiation heat transfer rate W/m^2
q_{sc}	Solar radiation absorbed within the cover of the greenhouse W/m^2
q_{ss}	Solar radiation absorbed within the soil W/m^2
q_{tr}	Transmission heat transfer W/m^2
S	Absorbed solar radiation
S_c	Surface area of greenhouse envelop m
S_s	Surface area of greenhouse soil m
T	Temperature °C
ΔT	The temperature difference between a greenhouse and the outside air ℃
t	Time
U	Overall heat loss coefficient W/m^2.K
V	Velocity, m/s
z	Soil depth of layer m

Greek symbols

α	Solar attitude angle
α_c	Cover absorptivity of solar radiation
α_{ct}	Cover absorptivity of thermal radiation
α_s	Soil surface absorptivity of solar radiation
α_{st}	Soil surface absorptivity of thermal radiation
ρ	Density
τ	Transmittance
σ	Stefan-Boltzmann constant

Subscripts

0	1 cm soil layer thickness
u	50 cm soil layer thickness
a	Ambient air
c	Cover
c - a	Cover to ambient air
f	Floor area
G	Glass
i	Inside
i - c	Inside air to cover
s	Soil
s - 1	Soil surface to sub-layer
s - i	Soil to inside air
sky	Sky
e	Experimental
th	Theoretical

Abbreviations

PE	Polyethylene
PP	Polypropylene
BUB	Air bubble film (Solawrap)
N	North
E	East
S	South
W	West

ستائر حرارية متحركة لحفظ الطاقة داخل البيت الزجاجي

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الخلاصة – في هذا العمل ، تم تصميم واختبار ستائر حرارية متحركة لغرض تقليل فقدان الحرارة في بغداد خلال ليالي الشتاء. تم اختبار ثلاثة أنواع من الستائر الحرارية المتحركة اوتوماتيكيا لتقليل فقدان الحرارة داخل البيت الزجاجي. وكانت مساحة الغطاء الشفاف ٢,٢٩ متر مربع و ٤ ملم سمك الغطاء الزجاجي. تم صياغة النموذج الرياضي لأربعة أجزاء هي الهواء الداخلي، الغطاء الشفاف، سطح التربة، وطبقة التربة التحتية. أظهرت نتائج الستائر الحرارية أن متوسط درجة حرارة الهواء الداخلي خلال الليل لغطاء البولي إيثيلين والبولي بروبيلين والغطاء الفقاعي كانت ١,٨ °س ، ٣,١٠ °س ، ٥,١٢ °س على التوالي بينما البيت الزجاجي بدون ستائر كان ٩,٥ °س. واظهرت هذه النتائج ان الغطاء الفقاعي كان أكثر فعالية في توفير الطاقة من البولي بروبلين وغطاء البولي ايثيلين. تم التوصل إلى توافق جيد بين النموذج الرياضي والقيم المقاسة (معدل الخطأ للجذر التربيعي النسبي اقل من ٥ %). تبين ان الانواع المقترحة المختلفة للستائر كانت جيدة في تخفيض الخسائر الحرارية، والتي بلغت حوالي ٢١.٧ % مقارنة مع بيت زجاجي بدون ستائر.

الكلمات الرئيسية – بيت زجاجي ، ستائر حرارية ، نموذج رياضي ، توفير الطاقة ، ستائر متحركة.