The Experimental Determination of The Impact of Overall Heat Consumption Coefficient and Thermal Screens on Heat Saving in Plastic Greenhouses

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ABSTRACT

This study was conducted to experimentally determine the effect of thermal screens used for heat saving and overall heat consumption coefficient on heat loss in greenhouses. The trial was established in three different lettuce greenhouses with 150 m² in floor size using different plastic covering materials between January and April. Hot air vent heaters were used for heating. The heaters were positioned 30 cm above ground level. The heating was done between 08.00 p.m. and 05.00 a.m. Plant level and roof level as well as external temperature and relative humidity were measured with data loggers. These measurements were used to statistically calculate overall heat consumption coefficient based on wind speed. The results demonstrate that thermal screens created a resistance against heat loss, thus reducing heat losses. The effect of thermal screens on heat loss depending on the wind speed was also determined. It was found out that heat saving ratios in greenhouses varied between 8% to 22% under very low wind speeds and between 17% - 36% under a wind speed of 4 m s⁻¹.

Plastik Seralarda Toplam Isı Tüketim Katsayısı ve Isı Perdesinin Isı Tasarrufuna Etkisinin Deneysel Olarak Belirlenmesi

ÖZET

Bu çalışmada, seralarda ısı tasarrufu için kullanılan ısı perdelerinin etkinliği ve toplam ısı tüketim katsayısı deneysel olarak araştırılmıştır. Araştırma Ocak ve Nisan ayları arasında farklı plastik örtü malzemeleri ile kaplı 150 m² taban alanı olan üç farklı marul serasında gerçekleştirilmiştir. Sera ısıtmasında sıcak hava üflemeli ısıtıcılar kullanmıştır. Isıtıcılar zemin seviyesinden 30 cm yukarıda konumlandırılmıştır. Isıtma 08.00-05.00 saatleri arasında yapılmıştır. Bitki seviyesi ve çatı seviyesinin yanı sıra dış sıcaklık ve bağıl nem değerleri, veri kaydediciler ile ölçülmüştür. Bu ölçümler, rüzgâr hızına dayalı toplam ısı tüketim katsayısını istatistiksel olarak hesaplamak için kullanılmıştır. Sonuçlar, ısı perdelerinin ısı kaybına karşı bir direnç oluşturduğunu ve böylece ısı kayıplarını azalttığını göstermektedir. Aynı zamanda ısı perdelerinin, rüzgâr hızına bağlı olarak ısı kaybına etkisi de belirlenmiştir. Seralarda ısı tasarrufu oranlarının çok düşük rüzgâr hızlarında %8 ile %22 arasında ve 4 m s⁻¹ rüzgâr hızında %17-36 arasında değiştiği hesaplanmıştır.

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INTRODUCTION

One of the most critical parameters in agricultural production is environmental conditions. It is of vital importance to ensure and monitor suitable climatic conditions for various controlled agricultural structures and production systems such as greenhouses (Çaylı et al., 2018).

Greenhouse heating remarkably improves product

quality and efficiency (Tantau, 1983). In order to increase quantitative and qualitative efficiency, greenhouses must be heated when daily average external temperature is under 12 °C (von Zabeltiz, 1992). Plants usually adapt to average temperatures between 17 °C to 27 °C in greenhouse cultivation, and their optimal temperatures vary between 15 °C to 20 °C at night and 22 °C to 28 °C during the day (Castilla and Hernandez, 2007). Greenhouse heating is one of the most energy-consuming activities during winter.

Heating in greenhouses increases product yield, quality and quantity. Especially in greenhouses heated in the Mediterranean coastline, two-fold increase in productivity can be achieved. However, the need for heat energy increases in greenhouses where heat preservation measures are not taken and an average of 100 kWh m-2 heat energy is needed depending on the climate values of the region during the production period (Baytorun and Güğercin, 2015).

Insufficient heating may affect the growth duration, efficiency, quality and amount negatively (Santamouris et al., 1994). Overall heat consumption coefficient is one of the main parameters in the calculation of heat consumption. It varies depending on structural properties of the greenhouse, covering material, wind speed and external climate conditions. The heat stored by the plants and soil at night affects the energy balance in a greenhouse. However, a study by Teitel et al. (2009) demonstrated that this impact creates a slight difference and can be ignored in the calculation. Heat consumption is equal to the heat loss in a greenhouse. In other words, overall amount of heat transmitted from a greenhouse to the external environment through convection, conduction and radiation must be brought back to the greenhouse, which requires the determination of overall heat consumption coefficient (U_{cs}).

Main decisive factors on overall heat consumption coefficient (U_{cs}) are heating system, greenhouse covering material, external climate conditions and greenhouse equipment (Von Zabeltiz, 2011; Baytorun, 2016). U_{cs} value in a greenhouse depends on the following factors: (1) The condition and type of covering material (wet or dry), (2) the convection heat exchange mechanism at the inside and the outside of the cover (3) Thermal radiation (long wave) transfer (sky conditions), (4) Air tightness (5) The surface area of the covering material, (6) Greenhouse type (structure and geometry) and floor area, (7) The existence of a thermal screen (Papadakis et al., 2000).

In view of environment and production costs, conservation of heating energy is as important as heating itself. Heat energy saving is about 37% when energy curtains are used (Baytorun and Zaimoglu, 2018). But the various theoretical heat saving methods applied to minimize heating costs in greenhouses and to maximize efficiency do not reach the intended levels due to insufficient sealing and insulation (Çaylı et al., 2016).

The tightness of a greenhouse and quality of the covering material is a vital factor. A covering material must possess high transmittance for a photosynthetic active radiation (PAR) at a wavelength of 400 – 700 nm and low transmittance for FIR at a long wavelength of 3000 – 20000 nm (Von Zabeltitz, 2011). Double layer covering materials are used in greenhouses to prevent heat loss caused by covering material. However, these are not recommended because they reduce solar radiation transmittance (Öztürk, 2008). Compared to single layer PE, double layer PE covering material reduce fuel consumption by 40% (Nelson, 2003). Whether normal PE or covering materials with durable UV and IR should be used is one of the main issues in plastic greenhouses (Baytorun et al., 1994). Materials with high light conduction and low IR transmittance are preferred in order to keep thermal energy in a greenhouse (Hemming, 2005). Baytorun et al. (1994) report that the temperature in a greenhouse with a covering material containing UV+IR is higher by 0.5°C compared to other greenhouses. Another covering material used in greenhouses is PC sheets. First used during 1970s, PC materials have become widespread (Noble and Holder, 1989). Produced as hard and flat sheets, PC sheets offers a sufficient insulation capacity depending on its width of air gap. Similar to glass, PC materials are impermeable for long wave radiation (Waaijenberg, 2004). Although double layer covering materials significantly reduce heat losses, they also cause aa light block. Alternatively, a moving screen can be installed within the greenhouse and it can be drawn horizontally at night to reduce heat losses, which saves heat by 40% (Critten and Bailey, 2002).

The tightness of thermal screen heavily influences heat consumption (Van de Braak et al., 1997). Qingfa and Jing (2002) compared a greenhouse with a double plastic covering material and a double layer thermal screen (consists of the film polythene and film plating aluminum) in terms of their impacts on temperature, light level and energy saving. They found out that the double layer thermal screen offered higher heat and energy saving and that heating started one month later than usual in the greenhouse. In addition, wind protection is an important factor when it comes to convective energy losses caused by wind speed in a greenhouse (Kittas, 1986). Thermal screen is an efficient heat protection method in reducing overall heat consumption coefficient. Thermal screens can reduce U_{cs} and save energy by 30% (Geoola et al., 2009). However, ventilation heavily influences heat saving aspect of thermal screens (Meijer, 1980). Thermal screens mainly decrease heat transfer rate in an environment and offer an additional thermal resistance (Arinze et al., 1986). Aluminum thermal

screens reduce radiation conductivity (Teitel and Segal, 1995). Thermal screens can help save energy in greenhouses. The saving rate is reported as 22% to 30% by Le Quillec et al. (2005), 40% by Critten and Bailey (2002), 70% by Chandra and Albright (1980), 52% by Jolliet et al. (1984), 60%–80% by Arinze et al. (1986), 60%–70% by Short and Pang (1990), and 58% by Mihara and Hayashi (1979). Baytorun et al. (1994) inform that a greenhouse with an aluminum thermal screen is higher by 3.4 °C compared to a greenhouse without a screen.

The heat power requirement in greenhouses is defined as the heat load which must be produced by the heating system in order to provide the desired temperature value in the greenhouse at a certain external temperature value (Akyuz et al., 2017).

The heat requirement calculations based on daily average temperature values give incorrect results when the temperature in the greenhouse is kept high or low. Therefore, the determination of the heat requirement based on hourly values gives more accurate results (Baytorun et al., 2018). For example, where the average outside temperature is 15 °C, when the temperature in the greenhouse is 15 °C, it is assumed that there is no heating requirement for that day. However, when the average daily temperature is 15 °C, the temperature can vary between 10-20 °C during the day. For this reason, the calculations made by using the average values can be misleading (Baytorun, 2016). Baytorun et al. (2016) Have developed an expert system that makes calculations based on scientific data in modeling and decision making of heating systems in greenhouses.

This study focuses on the determination of saving rates under different wind speeds in terms of overall heat consumption coefficient of the covering materials and the use of thermal screen in three different greenhouses with three different covering materials.

MATERIALS and METHODS

This study was conducted in greenhouses at Faculty of Agriculture at Kahramanmaras Sutcu Imam University located at 37° 35' 29.54"N and 36° 48' 10.98"E and 468 m above sea level. The experimental greenhouses were located at 10 km away from Kahramanmaras city center and 1000 m away on the west side of the university campus. Three different greenhouses with identical sizes were used in the study. GH-1 was covered with single layer polyethylene (PE), GH-2 was covered with double layer PE, and GH-3 was covered with polycarbonate (PC). Single layer of PE was used for roof covering in all greenhouses. The roof covering material has been selected as single layer of PE for high light transmittance. The technical properties of the greenhouses are given in Table 1.

Bonar TF TFE PH-55 aluminum polyester thermal screen was used in order to determine the heat saving activity in the greenhouses. The catalogue of the producing company states that the light transmittance, energy saving rate and shading rate of the thermal screen is 45%, 55% and 45%, respectively. Thermal screens closed at 07.00 p.m. and opened at 05.00 a.m. in order to determine their energy saving rates. They were placed under the roof truss at a height of 2.80 m above the ground level on steel wires, each of which were lined at a range of 2 m. The efficiency of thermal screen was tested for two different conditions, leaky and tightness (Fig. 1). This study measured the greenhouse air temperature and relative humidity of a greenhouse as well as external temperature, relative humidity and wind speed.

Table 1. The technical properties of the greenhouses

| Properties	GH-1	GH-2	GH-3
Length (m)	20.0	20.0	20.0
Width (m)	7.5	7.5	7.5
Side wall height (m)	3.0	3.0	3.0
Ridge height	5.0	5.0	5.0
Floor area (m²)	150	150	150
Covered surface area (m²)	352.6	352.6	352.6
Covering material additives	UV+IR+EVA	UV+IR+EVA	UV
Thickness of covering material (mm)	0.3	0.3	4.0
Ventilation area (m²)	30	30	30
Ventilation type and place	Passive/Roof	Passive/Roof	Passive/Roof
Side wall covering material	Single layer PE	Double layer PE (5 cm spacing)	PC (double layer, 0.4 cm spacing)
Roof covering material	Single layer PE	Single layer PE	Single layer PE
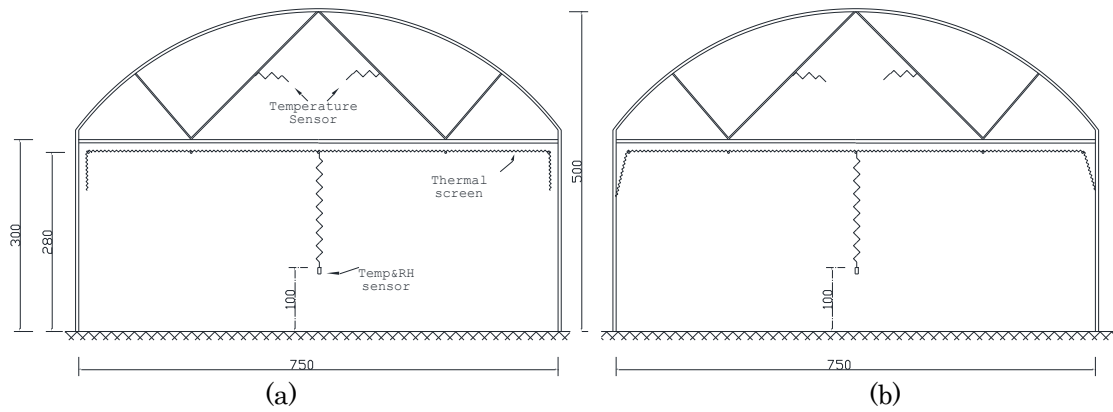
Fig. 1 The position of thermal screen (a) leaky (b) tight

Temperature and relative humidity were measured via HOBO U12 (Onset Corp., MA, USA) data loggers. Their temperature ranges were between -20 °C and +70 °C and sensitivity was ± 0.35 °C. Their relative humidity measurement range was between 5% and 95% and sensitivity was 2.5%. These devices were calibrated by the producing company. The meteorology station (TFA Dostmann GmbH & Co. KG, Mannheim, Germany) used for the measurement of external temperature, humidity and wind speed was positioned 20 m away on the eastern side of the greenhouses in order to prevent it from being affected by any turbulences caused by the experimental greenhouses. Anemometer used for the measurement of wind speed was controlled and calibrated. The meteorology station measures temperature between - 40 °C to 80 °C and at an accuracy of ± 1 °C and sensitivity of 0.1 °C, and measures relative humidity between 0% to 99%, at an accuracy of ± 5% and sensitivity of 1%. Greenhouse air temperature was measured via data loggers at a height of 1 m above ground level and temperature sensors positioned at 10 different points on the center of roof gap. Measurement values of the data logger were transferred to a Microsoft Excel file. Mean values were obtained separately as plant level and roof level. In order to reach average values, arithmetic means of values taken for plants at 6 different points at a height of 1 m above ground level and for the roof height at 4 different points at a height of 4 m were calculated at an interval of 15 minutes. External wind speed was measured via wireless anemometer connected to the main console of the meteorology station. Average and maximum wind speed measurement values were automatically logged by a device at an interval of 10 minutes and transferred from the meteorology station to the computer. Afterwards, these 10-minute values were used to convert hourly average wind speed values. The energy consumption of electric heaters used to heat greenhouses was measured in kWh by a three-phase electrometer (Makel T510, Istanbul, Turkey) with non-volatile memory. When the greenhouses were heated, hourly energy consumption was monitored by a camera positioned in front of an electrometer, and these values were used for the measurement. The heaters are positioned 30 cm above ground level. The heating was done between 08.00 p.m. and 05.00 a.m.

Overall energy consumption of the heaters was considered equal to the energy consumption value (Q) used in the calculation of overall heat consumption coefficient. Accordingly, kWh values taken from the electrometer at certain points were considered as the overall energy consumption value to be used in the calculation of overall energy consumption and overall heat consumption coefficient (U_{cs}) in the greenhouse. Overall heat consumption coefficient (U_{cs}) in a greenhouse can be calculated by limiting convection and radiation heat transfer if heat transfer rate, surface area, ambient and external temperatures are known or calculated (Öztürk and Başçetinçelik, 2003). In this study, overall heat consumption coefficient (U_{cs}) was calculated according to Equation 1 given by (Von Zabeltitz, 2011; Baytorun, 2016).

$$Q = U_{cs} \times A_y / A_t \times (t_i - t_o) \qquad (1)$$

Here

$$U_{cs} = (Q \times A_t) / [(A_y) \times (t_i - t_o)] \qquad (2)$$

In this equation;

Q = Overall heat consumption, W

U_{cs} = Overall heat consumption coefficient, W m^{-2} K^{-1}

A_t = Greenhouse floor area, m^2

A_y = Greenhouse surface area, m^2

t_o = Outside temperature, K

t_i = Greenhouse ambient temperature, K

Air tightness of thermal screens is defined as Air Tightness Efficiency (ATE) in this study and calculated via the Equation 3 (Von Zabeltitz, 1988; Öztürk, 2008).

$$ATE = (t_t - t_o) / (t_i - t_o) \qquad (3)$$

In this equation;

ATE = Air tightness efficiency of thermal screen

t_t = Temperature between thermal screen and roof, °C

t_o = Outside temperature, °C

t_i = Greenhouse air temperature (temperature under screen), °C

The amount of heat saving in a greenhouse with thermal screen is calculated via Equation 4 (Chandra and Albright, 1980).

$$IPT = [(Q_{ns} - Q_s)/Q_{ns}] \times 100 \qquad (4)$$

In this equation;

IPT = Heat saving of thermal screen, %

Q_{ns} = Heat consumption in a greenhouse without a thermal screen, W m^{-2}

Q_s = Heat consumption in a greenhouse with a thermal screen, W m^{-2}

RESULTS and DISCUSSION

The relationship between U_{cs} value and wind speed obtained as a result of measurements in the greenhouse without and with a thermal screen is given in Fig. 2a and Fig. 2b, respectively.

When Fig. 2a is analyzed, U_{cs} value in the greenhouses covered with single layer PE and PC are equal to each other and higher than the greenhouse covered with double layer PE if the wind speed is 3.6 m s^{-1}. For a lower wind speed (< 3.6 m s^{-1}), although U_{cs} value is lower in a PC greenhouse compared to single layer PE greenhouse, U_{cs} value in PC greenhouse increases at a higher level compared to single layer PE greenhouse as the wind speed increases.
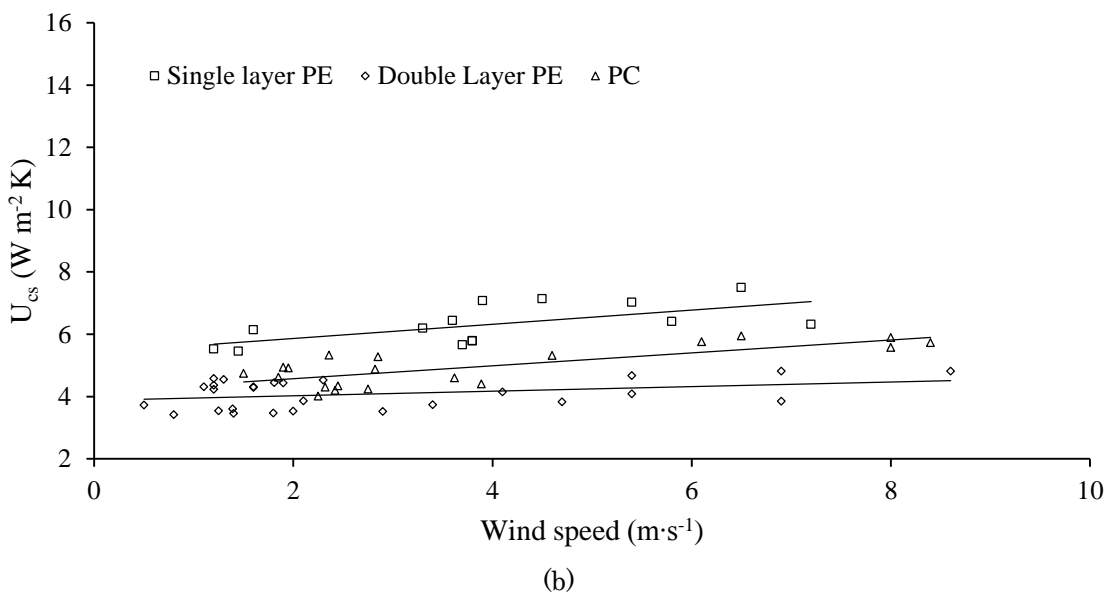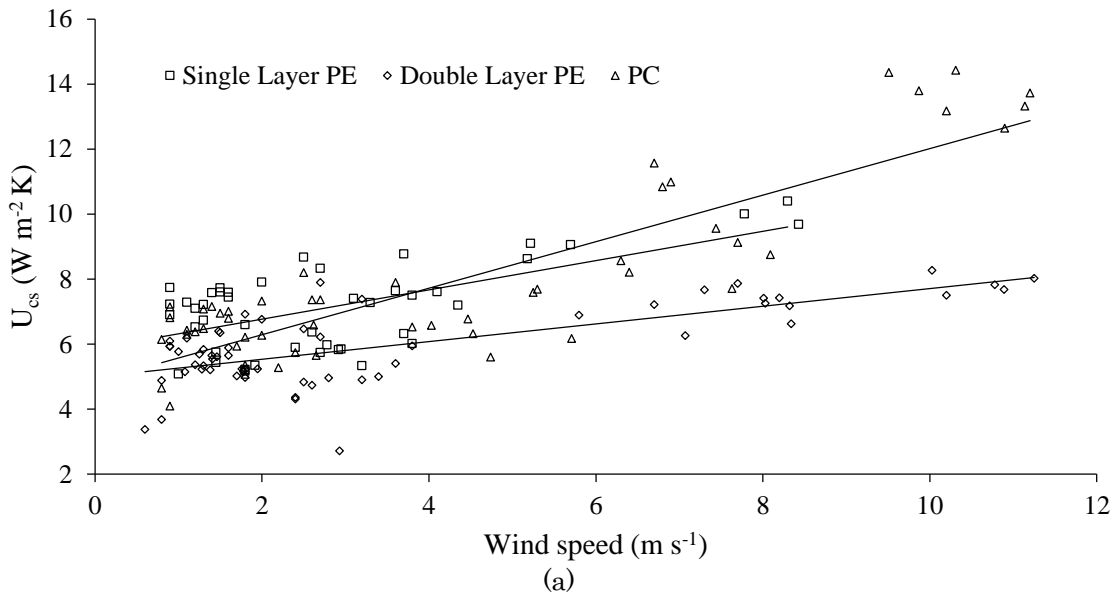

(a)

(b)

Fig. 2 U_{cs} values based on the wind speed; (a) Without a thermal screen, (b) With a thermal screen

Fig. 2b demonstrates that an increase in the wind speed does not significantly cause an increase in the overall heat consumption coefficient. The slope of the line for the greenhouse with a thermal screen is less compared to the one without a thermal screen, indicating that thermal screen prevents heat transfer from the greenhouse to the outside environment under high wind speeds. A regression analysis was performed to linearly determine the relationship between wind speed and U_{cs} value as shown in Table 2.

When the slopes of the lines belonging to the equations obtained via regression analysis are analyzed, in the greenhouses without a thermal screen, the changes in U_{cs} values reach the highest level for PC greenhouse (0.72) and remain at the lowest level for double layer PE greenhouse (0.27). On the other hand, in the greenhouses with a thermal screen, the highest level is observed in single layer PE greenhouse (0.23) while the lowest level belongs to double layer PE greenhouse (0.07).

The results obtained by regression analysis showed that there was a significant relationship between wind speed and U_{cs} value in the case of not using thermal screen ($P<0.01$). In other words, the value of U_{cs} increases with the increase of wind speed. The relationship between wind speed and U_{cs} value was not statistically significant ($P>0.05$). In other words, the value of U_{cs} is not affected by the increase in wind speed.

Findings show that thermal screen is effective against greenhouse heat losses at increasing wind speeds.

U_{cs} values calculated under different wind speeds for different covering materials in greenhouses with and without a thermal screen are given in Table 3.

Table 2. Regression equations for overall heat consumption coefficient and wind speed values

Application	Equation	R^2
Single layer PE (Without thermal screen)	$U_{cs}= 5.87 + 0.45v_w$	0.36
Single layer PE (With thermal screen)	$U_{cs}= 5.41 + 0.23v_w$	0.40
Double layer PE (Without thermal screen)	$U_{cs}= 5.00 + 0.27v_w$	0.49
Double layer PE (With thermal screen)	$U_{cs}= 3.90 + 0.07v_w$	0.12
PC (Without thermal screen)	$U_{cs}= 4.87 + 0.72v_w$	0.76
PC (With thermal screen)	$U_{cs}= 4.17 + 0.21v_w$	0.59

Table 3. Overall heat consumption coefficients based on covering materials under different wind speeds

Material	U_{cs} (W m^{-2} K^{-1})		
	0 m s^{-1}	4 m s^{-1}	10 m s^{-1}
Single layer PE	5.9	7.7	10.4
Single layer PE + thermal screen	5.4	6.3	7.7
Double layer PE	5.0	6.1	7.7
Double layer PE + thermal screen	3.9	4.2	4.6
PC (4 mm)	4.9	7.8	12.1
PC (4 mm) + thermal screen	4.2	5.0	6.3

Various researchers report that U_{cs} values in a single layer PE greenhouse without a thermal screen vary between 6.5 to 9.5 W m^{-2} K^{-1} (Tantau, 1977; Takakura, 1982; Nijskens et al., 1984; Weimann, 1984; Bailey, 1988; Baytorun, 2000) and between 2.8 to 3.7 W m^{-2} K^{-1} with a thermal screen (Bailey, 1977; Mihara and Hayashi, 1979; Özturk and Başçetinçelik, 2003; Öztürk, 2008). On the other hand, some researchers report that U_{cs} values in a double layer PE greenhouse without and with a thermal screen vary between 4.0 to 6.0 W m^{-2} K^{-1} and 2.5 to 4.0 W m^{-2} K^{-1} (Tantau, 1977; Takakura, 1982; Bailey, 1988; Zhang et al., 1996; Papadakis et al., 2000; Cemek, 2002).

It is also reported in the literature that U_{cs} value in a PC greenhouse varies between 3.2 to 4.8 W m^{-2} K^{-1} (Takakura, 1982; Nijskens et al., 1984; Bailey, 1988; Von Zabeltitz, 1988; Nelson, 2003; Yağcıoğlu, 2009). The results obtained in the single layer PE greenhouse without a thermal screen in this study display similarity with other results in the literature. However, the fact that values obtained with a thermal screen is higher than other results in the literature may result from inefficient tightness of thermal screens used in the experimental greenhouses. The results obtained for the relationship between U_{cs} value and wind speed in the greenhouse with double layer covering material comply with those reported by other researchers. U_{cs} values calculated for PC greenhouse without a thermal screen are higher than the values reported by other researchers. When a thermal screen is used, U_{cs} values demonstrate that increasing wind speed is less effective compared to the conditions without a thermal screen. Because the thermal screen

prevents heat losses occurring at the points of junction on the roofs of PC sheets, U_{cs} value remained at a lower level when a thermal screen is used. In addition, PC material is produced as a sheet of 2.10 m. Their low width leads to numerous joints in greenhouse covering.

Since sealing of joints are not used for the preservation of tightness at vertical edges of PC sheets in this greenhouse, U_{cs} value may have increased as a result of wind speed causing heat loss.

The impact of thermal screen on heat saving

In order to determine the air tightness efficiency (ATE) of thermal screens, the temperatures under and on the screens as well as external temperatures were used to reach calculations based on Equation 3 when the screens are closed. Leaky and tight thermal screens were installed in the greenhouse during the research process. However, due to technical facilities, single layer PE greenhouse was tested under a leaky condition while PC greenhouse was tested under a tight condition. Average values and calculations obtained from the measured data are given in Table 4.

Table 4. Average values when a thermal screen is used in the greenhouses

Greenhouse	Wind speed (m s⁻¹)	Temperature (°C)			U_{cs} (W m⁻² K⁻¹)	ATE
		1 m	Roof	External		
Single layer PE (leaky)	2.83	14.09	13.03	9.05	5.98	0.74
Double layer PE (leaky)	1.26	16.23	14.99	10.58	3.98	0.75
Double layer PE (tight)	2.06	17.44	14.86	12.32	3.21	0.50
PC (tight)	3.23	15.33	12.36	10.54	4.47	0.40

(Meyer, 1981) reported ATE as 0.27. The values calculated in this study is higher than that of (Meyer, 1981). This is because, as shown in Fig. 1, the thermal screen was drawn to cover the side wall at a height of 0.50 to 0.80 m. Furthermore, the side walls of PE greenhouses may wave under high wind speeds if they are not properly stretched, which may have caused air leakage and decreased the efficiency of the thermal screen.

Graphs and equations belonging to the regression analysis for the determination of the relationship between wind speed and thermal screen efficiency in Fig. 3.
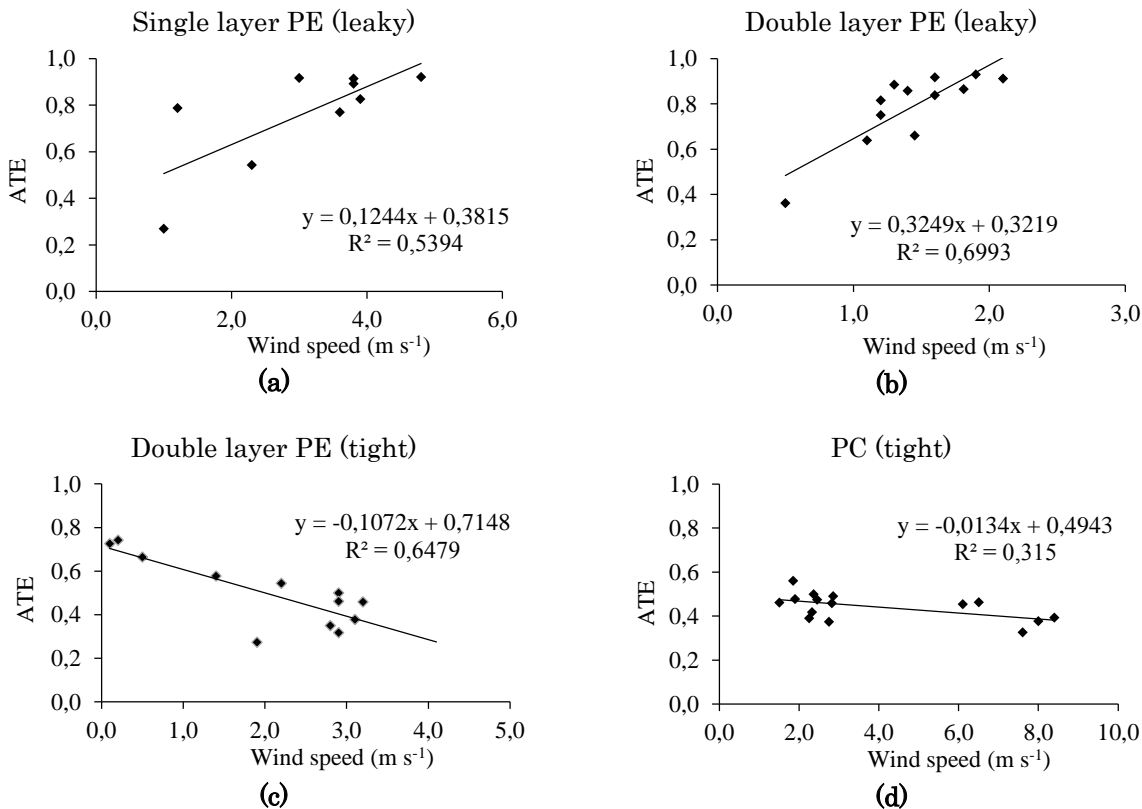

Fig. 3 Air tightness efficiency under different wind speeds (a) single layer leaky PE (b) double layer leaky PE (c) double layer tight PE (d) tight PC

It can be observed in Fig. 3 that ATE line varies depending on the tightness of the thermal screen. ATE value of the thermal screen used in leaky condition changes as the wind speed increases, and it cannot become efficient after the wind speed reaches a certain level. On the other hand, regression equations in tight condition were found negative (-), which means ATE value is inversely proportional to the increasing wind speed. Overall heat consumption coefficients were used to calculate overall heat losses as shown in Fig. 4.
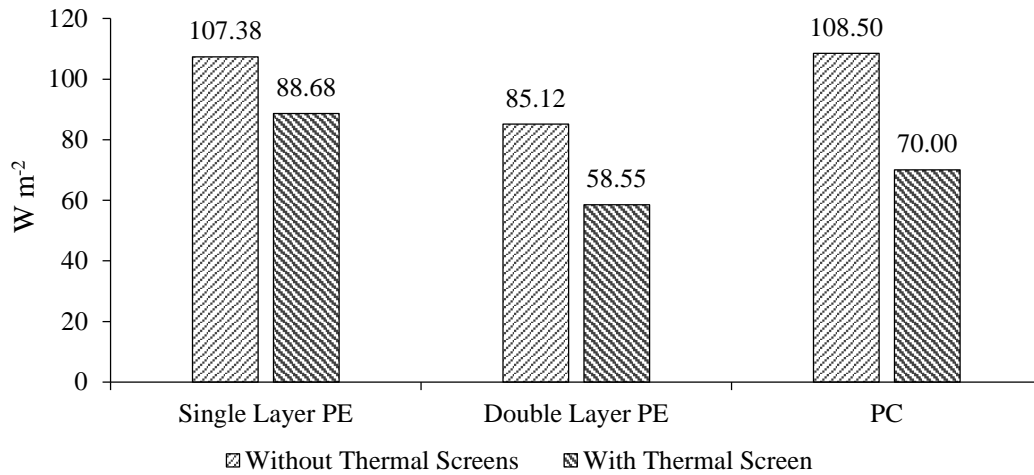

Fig. 4 Overall heat loss in greenhouses with different covering materials under a wind speed of 4 m s^{-1}

In Fig. 4, the highest heat loss was observed in single layer PE greenhouse while the lowest level belongs to double layer PE greenhouse. Thanks to the thermal screen, overall heat loss in the greenhouses was reduced by 36%, 31% and 17% in PC, double layer PE and single layer PE, respectively.

Several researchers in the literature reported that a thermal screen could reduce heat loss by 20% to 70% (Bailey, 1977; Mihara and Hayashi, 1979; Chandra and Albright, 1980; Fuller et al., 1984; Meyer, 1984; Jolliet et al., 1985; Arinze et al., 1986; Newell, 1986; Short and Pang, 1990; Pirard et al., 1994; Critten and Bailey, 2002; Le Quillec et al., 2005). However, these studies do not offer satisfactory information regarding the impact of covering material, wind speed and tightness of the thermal screen on heat saving. It must be noted that this study clearly demonstrates the significant impact of wind speed and tightness on the efficiency of thermal screen and heat saving.

Heat losses in the greenhouses depending on the heat amount, covering material and thermal screen under different wind speeds are shown in Fig. 5. Overall heat loss varies between 54 to 75 W m^{-2} under windless conditions while this rate varies between 65 to 168 W m^{-2} when the wind speed is 10 m s^{-1}.
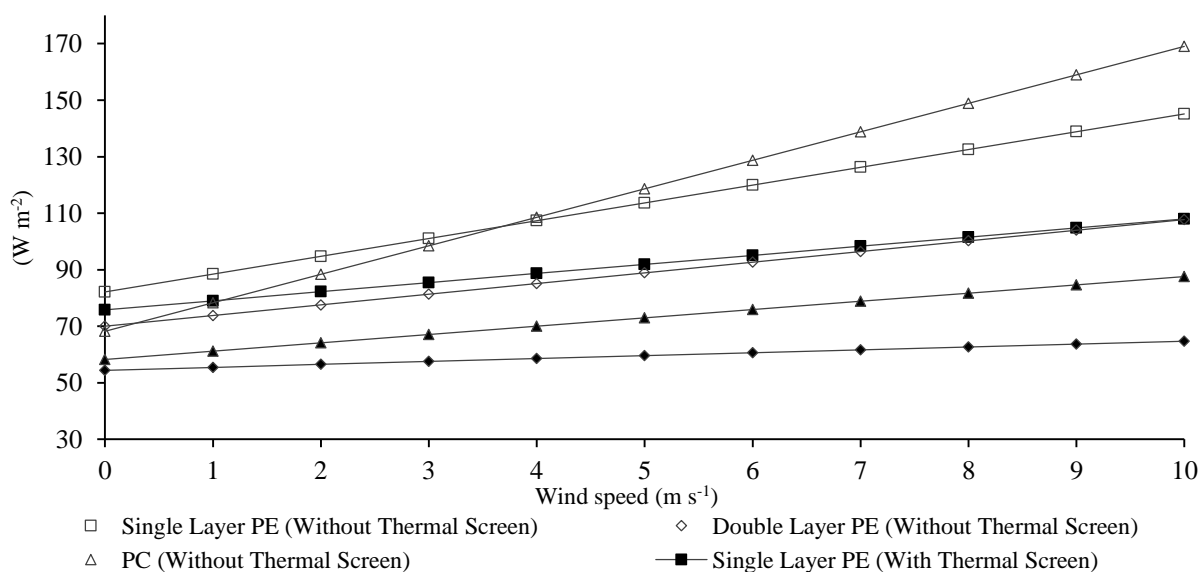

Fig. 5 Overall heat loss in the greenhouses with different covering materials under different wind speeds

The impact of wind remained at the lowest level in double layer PE greenhouse while it reached the highest level in PC greenhouse without a thermal screen. Increasing wind speed causes higher losses in greenhouses without a thermal screen compared to those with a thermal screen. Thermal screens reduced overall heat losses and thus provided heat saving for greenhouses.

CONCLUSION

It was found out in this study that U_{cs} value which was experimentally obtained observed to have increased at different rates under different wind speeds and covering materials. PC greenhouse was influenced more by the wind speed while double layer PE greenhouse was influenced less. Additionally, it was also demonstrated that a thermal screen could reduce heat losses caused by the wind speed and that this impact reached the highest level in PC greenhouse while it remained at the lowest level in single layer PE greenhouse.

Heat savings can be achieved with a variety of long-wave radiation-resistant coating materials, such as PC or double-layer covering materials. But double layer covering material reduce light penetration to greenhouse and may reduce yield and quality. For this reason, it is recommended that the roofing material is a single layer PE, for high light transmittance. In addition, heat saving through thermal screens is a commonly used method in cold climates. Because thermal screen reduces U_{cs} values, it will automatically reduce energy consumption. However, heat saving of thermal screens heavily rely on the properties of screen material, particularly tightness. Air tightness may cause the relative humidity to rise in the greenhouse. But, when heating, relative humidity may control in greenhouse. Thermal screens are used to reduce the impact of heating costs on production costs. Thus, tightness must be taken into consideration in the installation and operation of thermal screens.

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REFERENCES
Akyuz A, Baytorun AN, Cayli A, Ustun S, Onder D 2017. New Approaches to Required Heat Power for Designing the Greenhouse Heating Systems. K.S.U. Journal of Natural Sciences, 20(3): 209-217.

Arinze EA, Schoenau GJ, Besant RW 1986. Experimental and computer performance evaluation of a movable thermal insulation for energy conservation in greenhouses. Journal of Agricultural Engineering Research, 34(2): 97-113. doi: 10.1016/S0021-8634(86)80003-8

Bailey BJ 1977. Thermal Screens For Reducing Heat Losses From Glasshouses. Acta Horticulturae, 70(3): 26-34. doi: 10.17660/ActaHortic.1977.70.3

Bailey BJ 1988. Improved Control Strategies For Greenhouse Thermal Screens. Acta Horticulturae, 230(63): 485-492. doi: 10.17660/ActaHortic.1988.230.63

Baytorun A, Akyüz A, Üstün S 2016. Seralarda ısıtma sistemlerinin modellemesi ve karar verme aşamasında bilimsel verilere dayalı uzman sistemin geliştirilmesi. TÜBİTAK Proje(No: 114O533).

Baytorun AN 2000. Seralar (Çeviri) Çukurova Üniversitesi Ziraat Fakültesi, Yayın No:110, Adana, 402s,

Baytorun AN 2016. Seralar, Sera Tipleri, Donanımı ve İklimlendirilmesi (1 ed.) Nobel Akademik Yayıncılık, İstanbul, 444s

Baytorun AN, Abak K, Tokgöz H, Altuntas O 1994. Effect Of Different Greenhouse Covering Materials On Inside Climate And On The Development Of Tomato Plants. Acta Horticulturae, 336(14): 125-132. doi: 10.17660/ActaHortic.1994.366.14

Baytorun AN, Güğercin Ö 2015. Seralarda enerji verimliliğinin artırılması. Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 30(2): 125-136.

Baytorun AN, Zaimoglu Z 2018. Climate Control in Mediterranean Greenhouses IntechOpen, London, 167-181s

Baytorun AN, Zaimoğlu Z, Akyüz A, Üstün S, Çaylı A 2018. Comparison of Greenhouse Fuel Consumption Calculated Using Different Methods with Actual Fuel Consumption. Turkish Journal of Agriculture-Food Science and Technology, 6(7): 850-857.

Castilla N, Hernandez J. (2007). Greenhouse technological packages for high quality production. Acta Horticulturae: International Society for Horticultural Science (ISHS), Leuven, Belgium.

Cemek B 2002. Farklı Sera Örtü Malzemelerinin Bitki Büyüme, Gelişme, Verim ve Sera İçi Çevre Koşullarına Etkisi. OMU Fen Bil. Ens.,Tarımsal Yapılar ve Sulama ABD, Doktora Tezi, 168 s.

Chandra P, Albright LD 1980. Analytical Determination of the Effect on Greenhouse Heating Requirements of Using Night Curtains. Transactions of the Asae, 23(4): 994-1000. doi: 10.13031/2013.34703

Critten DL, Bailey BJ 2002. A review of greenhouse engineering developments during the 1990s. Agricultural and Forest Meteorology, 112(1): 1-22. doi: 10.1016/S0168-1923(02)00057-6

Çaylı A, Akyüz A, Baytorun AN, Üstün S, Boyacı S 2016. Determination of Structural Problems Causing Heat Loss with the Thermal Camera in Greenhouses. KSU Journal of Natural Sciences, 19(1): 5-14.

Çaylı A, Akyüz A, Baytorun AN, Üstün S, Mercanlı AS 2018. The Feasibility of a Cloud-Based Low-Cost Environmental Monitoring System Via Open Source Hardware in Greenhouses. KSÜ Tarım ve Doğa Derg, 21(3): 323-338. doi: 10.18016/ksudobil.341513

Fuller RJ, Sides R, Blackwell J 1984. A Thermal Screen System For Greenhouse Energy Conservation. Agricultural Engineering Australia, 27(1): 777-794.

Geoola F, Kashti Y, Levi A, Brickman R 2009. A study of the overall heat transfer coefficient of greenhouse cladding materials with thermal screens using the hot box method. Polymer Testing, 28(5): 470-474. doi: 10.1016/j.polymertesting.2009.02.006

Hemming S 2005. EFTE: ein hoch transparentes Bedachungsmaterial. Gärtnerbörse, 105(6): 16-17.

Jolliet O, Bourgeois M, Danloy L, Gay J-B. (1984). Test and Modelization of a Greenhouse Using Low Temperature Heating BT - First E.C. Conference on Solar Heating: Proceedings of the International Conference held at Amsterdam, April 30-May 4, 1984. Dordrecht.

Jolliet O, Bourgeois M, Danloy L, Gay J-B, Mantilleri S, Moncousin C 1985. Test of a greenhouse using low temperature heating. Acta Horticulturae, 170(1): 219-226. doi: 10.17660/ActaHortic. 1985.170.25

Kittas C 1986. Greenhouse cover conductances. Boundary-Layer Meteorology, 36(3): 213-225. doi: 10.1007/BF00118660

Le Quillec S, Brajeul E, Lesourd D, Loda D 2005. Thermal Screen Evalution In Soilless Tomato Crop Under Glasshouse. Acta Horticulturae, 691(1): 709-716. doi: 10.17660/ActaHortic.2005.691.87

Meijer J 1980. Reduction of Heat-Losses from Greenhouses by Means of Internal Blinds with Low Thermal Emissivity. Journal of Agricultural Engineering Research, 25(4): 381-390. doi: Doi 10.1016/0021-8634(80)90079-7

Meyer J 1981. Energy Saving With Mobile Thermal Screens. Acta Horticulturae, 115(1): 677-684. doi: 10.17660/ActaHortic.1981.115.76

Meyer J 1984. The influence of thermal screens on energy consumption of greenhouse. Garten Dauwissen Schaft, 49(1): 74-80.

Mihara Y, Hayashi M 1979. Studies on the insulation of greenhouses, 1: Overall heat transfer coefficient of greenhouses with single and double covering using several material curtains. Journal of Agricultural Meteorology, 35(1): 13-19.

Nelson PV 2003. Greenhouse Operation and Management (6 ed.) Prentice Hall, Raleigh, NC 27695, USA. , 692s

Newell A 1986. Improved Production With New Plastics And Fabrics. Australian Horticulture, 84(3): 48-52.

Nijskens J, Deltour J, Coutisse S, Nisen A 1984. Heat transfer through covering materials of greenhouses. Agricultural and Forest Meteorology, 33(2-3): 193-214. doi: 10.1016/0168-1923(84)90070-4

Noble R, Holder R 1989. Pot plant production under various greenhouse cladding materials. Journal of Horticultural Science, 64(4): 485-493.

Öztürk HH, Başçetinçelik A 2003. Energy and exergy efficiency of a packed-bed heat storage unit for greenhouse heating. Biosystems engineering, 86(2): 231-245. doi: 10.1016/S1537-5110(03)00134-X

Öztürk HH 2008. Sera İklimlendirme Tekniği Hasad Yayincilik, Istanbul,

Öztürk HH, Başçetinçelik A 2003. Effect of Thermal Screens on the Microclimate and Overall Heat Loss Coefficient in Plastic Tunnel Greenhouses. Turkish Journal of Agriculture and Forestry, 27(3): 123-134.

Papadakis G, Briassoulis D, Mugnozza GS, Vox G, Feuilloley P, Stoffers JA 2000. Radiometric and thermal properties of, and testing methods for, greenhouse covering materials. Journal of Agricultural Engineering Research, 77(1): 7-38. doi: 10.1006/jaer.2000.0525

Pirard G, Deltour J, Nijskens J 1994. Controlled operation of thermal screens in greenhouses. Plasticulture (France), 103(1): 11-22.

Qingfa C, Jing W 2002. Temperature and Energy-Saving Effects of Applying the Mobile Double Layers Thermal Screen in A Grcenhouse [J]. Transactions of The Chinese Society of Agricultural Engineering, 18(1): 111-114.

Santamouris M, Balaras CA, Dascalaki E, Vallindras M 1994. Passive Solar Agricultural Greenhouses - a Worldwide Classification and Evaluation of Technologies and Systems Used for Heating Purposes. Solar Energy, 53(5): 411-426. doi: Doi 10.1016/0038-092x(94)90056-6

Short TH, Pang T 1990. Heat transfer across a double acrylic greenhouse glazing. Paper - American Society of Agricultural Engineers, 90-4534.

Takakura T 1982. Heating, Ventilating and Cooling Greenhouses. Journal of Agricultural Meteorology, 38(1): 65-70.

Tantau HJ 1977. The Influence Of Single And Double Shelters On The Climate And Heat Consumption Of Greenhouses. Acta Horticulturae, 87(1): 119-124. doi: 10.17660/ActaHortic.1977.70.1

Tantau HJ 1983. Heizungsanlagen Im Gartenbau.Handbuch Des Erwerbsgärtners. Verlag Eugen Ulmer, Stuttgart, 258s

Teitel M, Barak M, Antler A 2009. Effect of cyclic heating and a thermal screen on the nocturnal heat loss and microclimate of a greenhouse. Biosystems engineering, 102(2): 162-170. doi: 10.1016/

j.biosystemseng.2008.11.013

Teitel M, Segal I 1995. Net Thermal Radiation Under Shading Screens. Journal of Agricultural Engineering Research, 61(1): 19-25. doi: 10.1006/jaer.1995.1026

Van de Braak NJ, Kempkes FLK, Bakker JC, Breuer JJG 1997. Application of simulation models to optimize the control of thermal screens. II Modelling Plant Growth, Environmental Control and Farm Management in Protected Cultivation 456(1): 391-398.

Von Zabeltitz C 1988. Energy conservation and renewable energies for greenhouse heating. Energy conservation and renewable energies for greenhouse heating., 3(1): 9-16.

Von Zabeltitz C 2011. Integrated Greenhouse Systems for Mild Climates: Climate Conditions, Design, Construction, Maintenance, Climate Control Springer Berlin Heidelberg, Berlin, Heidelberg, 285-311s

Von Zabeltiz C 1992. Energy-efficient greenhouse designs for Mediterranean countries. Plasticulture (France).

Waaijenberg D 2004. Design, construction and maintenance of greenhouse structures. International Symposium on Greenhouses, Environmental Controls and In-house Mechanization for Crop Production in the Tropics, 71(1): 31-42.

Weimann G 1984. Energiesparende Mannahmen in Foliengewächshausern. Deutscher Gartenbau, 38(1): 1569-1571.

Yağcıoğlu A 2009. Sera Mekanizasyonu Ege Üniv. Ziraat Fakültesi Yayınları, İzmir, 373s

Zhang Y, Gauthier L, de Halleux D, Dansereau B, Gosselin A 1996. Effect of covering materials on energy consumption and greenhouse microclimate. Agricultural and Forest Meteorology, 82(1-4): 227-244. doi: 10.1016/0168-1923(96)02332-5