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Overall Heat Transfer Coefficient Measurement of Covering Materials with Thermal Screens for Greenhouse using the Hot Box Method

핫박스를 이용한 온실 피복재 및 보온재의 조합에 따른 관류열전달계수 측정

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ABSTRACT
본 연구의 목적은 국내에서 상용되고 있는 온실 피복재 및 보온재의 조합에 따른 관류열전달계수를 핫박스를 이용하여 평가하는 것이다. 온실용 일중 및 이중 피복재와 이중 보온재의 조합에 대하여 야간천공복사 차단여부에 따른 관류열전달계수를 핫박스를 이용하여 실외에서 측정하였다. 처리조건은 일중피복, 이중피복, 이중피복과 이중 마트보온재 및 이중피복과 이중 다겹보온재의 조합조건과 천공복사 유무에 따른 조건이며 총 8가지이다. 제작된 핫박스는 상시 변화하는 외부의 기상조건하에서도 내부온도를 설정된 온도로 일정하게 잘 유지할 수 있었다. 온실 피복재 및 보온재의 관류열전달계수를 측정하는 실내용 측정장치는 반드시 야간천공복사를 모의할 수 있는 측정장치가 되어야 할 것이다. 야간복사를 차단함으로서 온실의 열 손실을 줄여 보온효과를 얻을 수 있을 것으로 분석되었다. 모든 피복방식에 대해 야간복사 차단장치 유무에 관계없이 높은 풍속에서의 관류열전달계수가 낮은 풍속에서보다 더 큰 것으로 나타났다. 본 연구에서 사용된 측정기법을 사용하면 국내에서 생산되는 피복재 및 보온재의 관류열전달 특성을 정량적으로 비교할 수 있을 것으로 기대된다.

Keywords: matt screens; multi layers screens; outside experiment; polyethylene film; shelter from sky radiation

I. INTRODUCTION

Achieving favorable environment in the greenhouses under cold winter or hot and sunny summer conditions has become one of the major challenges still facing designers and growers (Abdel-Ghany, 2011). The thermal environment of the greenhouse is based on the relative input and outflow of energy. Greenhouse heating is one of the most energy consuming activities during winter periods. The determination of the quantity of heat transmitted through the cover is an important thermal problem of greenhouses and its rational approach represents a valuable tool for many practical applications (Kittas, 1994). The selection of the cover material has a tremendous influence on the crop production capability of the greenhouse system (Giacomelli and Roberts, 1993).

The covering material is a basic factor influencing the energy consumption, the yield and the general economics of the greenhouse. Materials used as greenhouse covers (especially plastic films) are not spatially homogeneous. Only the measurement of several properties under certain conditions may provide data for assessing the quality of a covering material and for material comparison. In order to save energy by the greenhouse effect, a greenhouse covering material should possess good heat insulating characteristics, be transparent to visible radiation and opaque to the infrared (Geoola et al., 2009; Papadakis et al., 2000; Zabeltitz, 1992). Further energy saving measures for the construction of greenhouses can be attained by using different types of thermal screens (Geoola et al., 2009; Pirard et al., 1994; Plaisier, 1996). Screen materials are being used extensively in agriculture for conserving energy by reducing night radiation heat loss, and for reducing solar heat load by day. Measurements of their thermal properties are needed to determine the influence of screens on the heat loss coefficient. It is difficult for the horticulturists to choose from the

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many new materials which invade the market, the majority of which lack references regarding utilization. Practical tests must be carried out over long periods if the results are to be independent of climatic changes (Nijskens et al., 1984).

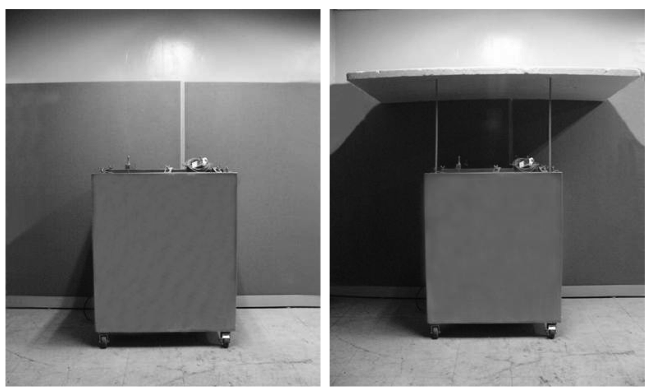
In order to calculate the heat load, to determine the capacity of heaters, the quantity of fuel needed for winter, it's necessary to find the exact value of overall heat transfer coefficient for the plastic film and thermal screens widely used in the country. Many researchers suggest an overall heat transfer coefficient, but these coefficients are very different because the coverings materials characteristics are different and have different additives, the wind speed is changing with time, the greenhouse type is not similar and the greenhouse environments (inside temperature, air leakage) are different. For many years, hot box facilities have been used for thermal testing of inhomogeneous components, even if they have been applied with different standards throughout the world. Today, hot boxes are reliable instruments for various types of measurements (Asdrubali and Baldinelli, 2011).

The objective of the present study was to investigate the overall heat transfer coefficient of greenhouse covering materials with or without thermal screens commonly used in the country under external conditions by using the hot box method.

II. MATERIALS AND METHODS

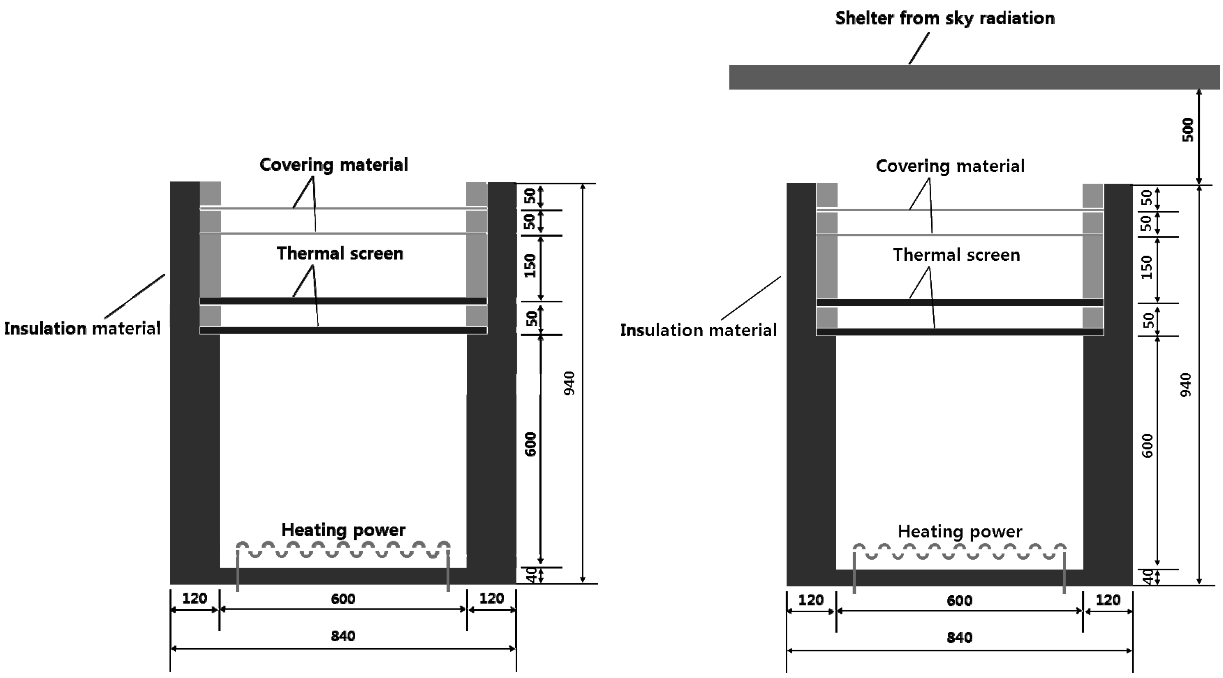
1. Experimental Apparatus

Regarding the measurement methods for the overall heat transfer coefficient, several standards propose the use of the hot box method. These standards were originally established for measuring rigid materials, but they also allow the measurement of thin film materials such as flexible plastic greenhouse covering materials (Papadakis et al., 2000). Fig. 1 shows the guarded hot box designed and built partially based on ASTM standards C 236-89. Fig. 1 (a) and (b) illustrate the hot box installed without and with shelter from sky radiation respectively. The technique used in the present work was inspired by work using guarded hot box (Feuilloley and Issanchou, 1996) to investigate the overall heat transfer coefficient of greenhouse covering materials with thermal screens widely used in the country. The walls of the box consist of 12 cm thick urethane for insulation. Parameters measured for analysis were obtained by using the hot box with dimensions shown in the Fig. 2. The shelter from sky radiation was installed 50 cm above hot box in order to measure the overall heat transfer coefficient by shelter which is polystyrene foam sheet with 5 cm thickness and 190 cm×180 cm size. The hot box has a heating system in its lower internal surface. The heating power is 500 W. The input power was measured by a wattmeter (POWER MANAGER, Korea). The inside hot box temperature can be predetermined by a voltage regulator for the heating input power. The power dissipated by the heater was measured every second. In order to study the overall heat transfer coefficient of the combined covering materials and thermal screens, space was made for placement of specimens at distances of 5, 15, 5 cm as shown in Fig. 2. The experiments were conducted to measure parameters relating to the hot box and the external climate. Temperatures at different locations inside and outside the box were measured and averaged using six HOBO sensors (ONSET, USA). For outside temperature two more HOBO sensors were set and their values also averaged in order to increase the accuracy of the measurements. The amount of heat loss dissipating through the hot chamber's wall was calculated by using the surface temperatures of the inner and outer of three walls measured by surface temperature sensors (UE-1530, Korea). Tests were made in dry state under external conditions. The trial was carried out at night, when the system was close to a steady state and the external climatic



(a)Without shelter (b) With shelter

Fig. 1 Pictures of hot box



(a) Without shelter (b) With shelter

Fig. 2 Schematic diagram of the hot box (Unit: mm)

conditions were stable (usually between 01:00 h, and 05:00 h) (Feuilloley and Issanchou, 1996). The measurement data were recorded from December 1, 2011 to April 20, 2012. The wind velocity was measured at the College weather station near the experiment place.

2. Theoretical Consideration

If our experimental apparatus is adiabatic and heat transfer through the cover material or cover material coupled with thermal screen is stable, it follows from thermal equilibrium theory. The overall heat transfer coefficient of U ($W \cdot m^{-2} \cdot K^{-1}$) should be calculated from the following equation:

$$U = \frac{Q}{A(T_i - T_o)} \tag{1}$$

where Q is energy required for heating (watts), A is area of the sample (m^2), Ti is inside air temperature of the hot box below the sample (℃), T_o is outside temperature (℃).

This equation summarizing the quantity of heat energy passing through a material per unit area and per unit of temperature difference between the two faces of the tested sample doesn't include heat loss through box's walls. Thus it is necessary to estimate the share of energy loss through the covering material by calculating the share of energy lost through the walls because the box is not adiabatic. The heat loss by air leakage was disregarded. Thus the energy balance of the box is given by:

$$Q = Q_r - Q_w \tag{2}$$

where Q_r is the heating power of the heater (watts) and, Q_w is heat loss through the walls (watts).

The value of U for the covering material is then:

$$U = \frac{Q_r - Q_w}{A(T_i - T_o)} \tag{3}$$

The heat loss through the walls is:

$$Q_w = \frac{\lambda S_w (T_p - T_x)}{L_w} \tag{4}$$

where S_w is walls surface area (m^2), λ is thermal conductivity coefficient of insulated material of urethane ($W \cdot m^{-1} \cdot K^{-1}$), T_p is surface temperature of the inner walls (℃), T_x is surface temperature of the outer walls (℃) and L_w is thickness of the hot box walls (m).

3. Material and Procedures

Table 1 shows the test conditions of eight treatments combined covering materials and thermal screens with and without shelter from the sky radiation used to determine the overall heat transfer coefficient. Covering material was polyethylene film and its thickness was 0.1 mm. Covering method was one layer and two layers by PE film. We applied two kinds of thermal screens installation. One was 2 layers of matt screen (600×300, 300×300 denier); another was two layers of multi layers screen (5 and 6 layers). All tests were performed with and without shelter. The inside setting temperature of the hot box was 15 ℃. All temperature and input power of electric heater were recorded after the steady state was reached for each test. Each treatment was repeated more than five times. The U value for each group was calculated by using the equation (3).

Table 1 Test matrix of covering materials with thermal screens and shelter

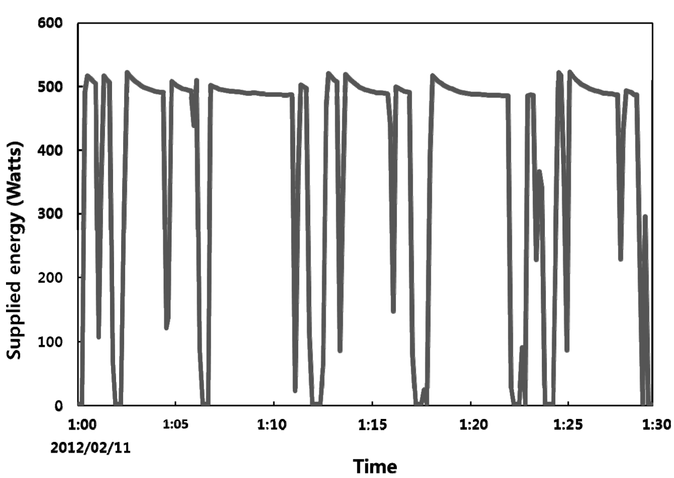
Treatment	Covering material	Thermal screen	Shelter
1L	1 layer of PE film	None	None
1LS	1 layer of PE film	None	Installed
2L	2 layers of PE film	None	None
2LS	2 layers of PE film	None	Installed
4LM	2 layers of PE film	2 layers of matt	None
4LMS	2 layers of PE film	2 layers of matt	Installed
4LX	2 layers of PE film	2 layers of multi layers	None
4LXS	2 layers of PE film	2 layers of multi layers	Installed

III. RESULTS AND DISCUSSION

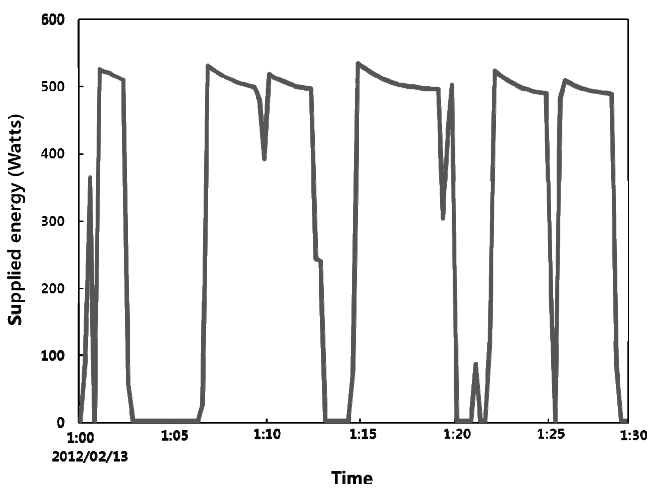
1. Operating Conditions of the hot Box

Fig. 3 shows the variation of supplied energy with time during 1:00 to 1:30 am on February 11 and February 13. The heating power was varied between 2.3 and 534.5 W. The 2.3 W of the minimum heating power was needed for maintaining the heating system. The 534.5 W of the maximum heating power was actual supplied energy which was slightly greater than the nominal capacity. The heat supplying interval at the low outside temperature was shorter than that at high outside temperature because the heat loss was different depending on outside temperature.

Fig. 4 shows the variation of inside hot box temperature and outside temperature. The inside hot box temperature during experiment was stable and uniform around the setting temperature of 15 ℃ while the outside temperature was varied between 0.1 to −3.5 ℃. It was concluded that the hot box had a proper operating environment for measuring the overall heat transfer coefficient.



(a) Low outside temperature (−3.9∼−0.2 ℃)



(b) High outside temperature (1.6−3.3 ℃)

Fig. 3 Variation of supplied energy with time

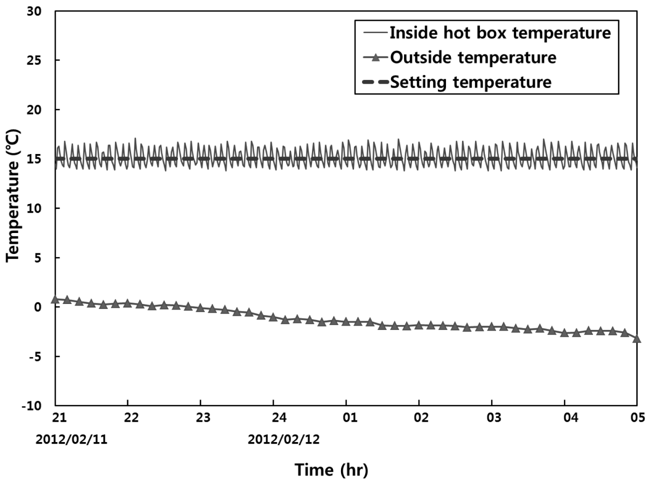


Fig. 4 Variation of inside hot box temperature and outside temperature

2. Variation of Overall Heat Transfer Coefficient

Fig. 5 shows the variation of the overall heat transfer coefficient in the different test conditions by shelter from sky radiation. The insulation effect of two layers covering material was 25 % comparing to one layer covering material, 57 % for two layers covering material coupled with two layers matt screen and 67 % for two layers covering material coupled with two layers multi layers screen. The coefficient measured without shelter was greater than that with shelter by around 20 % for one layer, 30 % for two layers, 12 % for two layers covering material coupled with two layers matt screen and 9 % for two layers covering material coupled with two layers multi layers screen. The ratio of heat loss of covering material coupled with thermal screen by using shelter was less than covering material without thermal screen. When we measure the overall heat transfer coefficients in a laboratory, it's necessary to establish the measuring system to be able to simulate the sky radiation. It was concluded that the insulation effect of greenhouse could be acquired by reducing the heat loss through blocking sky radiation because the overall heat transfer coefficient measured with shelter was lower than that without shelter for all 4 different covering treatments.

Fig. 6 shows the variation of the overall heat transfer coefficients in the different test conditions with the wind speed. High wind represents wind speed more than 2 $m \cdot s^{-1}$ and low wind represents wind speed less than 2 $m \cdot s^{-1}$ in

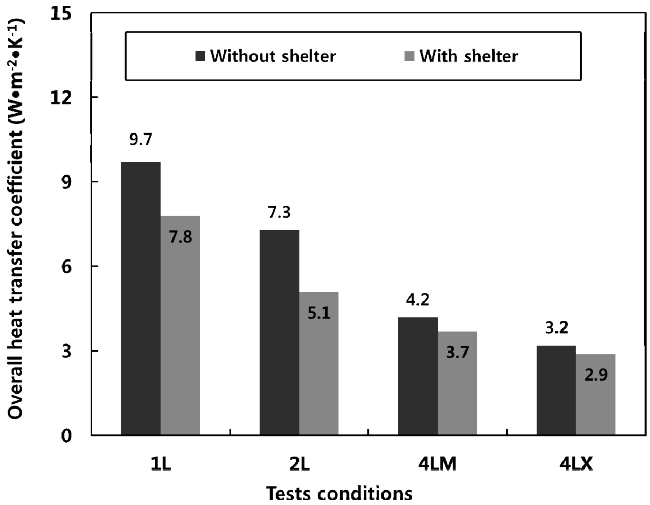


Fig. 5 Overall heat transfer coefficient in the different test conditions by shelter from sky radiation

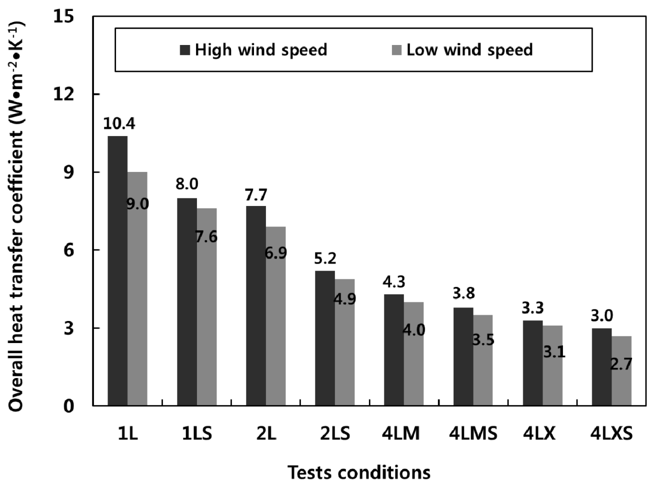


Fig. 6 Overall heat transfer coefficients in the different test conditions with the wind speed

Fig. 6. For all cases the overall heat transfer coefficients measured at high wind speed were greater than the coefficients at low wind speed. The coefficient measured at high wind speed was greater than that at low wind speed by around 14 % for one layer, 10 % for two layers, 8 % for two layers covering material coupled with two layers matt screen and 6 % for two layers covering material coupled with two layers multi layers screen. Even if the coefficients could not be compared directly because the actual wind velocities were different each other, the heat loss of covering material without thermal screen by wind was greater than that of covering materials coupled with thermal screens. It was

Table 2 Different overall heat transfer coefficients of polyethylene film ($W \cdot m^{-2} \cdot K^{-1}$)

Covering method	Seginer et al. (1988)[1]		Nijskens et al. (1984)[2]		Geoola et al. (2009)[3]		Feuilloley and Issanchou (1996)[4]	Present study[5]	
	Regular	With additives	Clear sky	Overcast sky	High wind	Low wind		High wind	Low wind
Single	10.0	9.5	9.0	7.2	9.7∼14.8	8.8∼13.6	10.2∼12.1	10.4	9.0
Double	7.3	6.9	6.4	4.8	-	-	-	7.7	6.9

[1]Results measured at wind speed limited to less than 2.5 $m \cdot s^{-1}$.
[2]Results measured at wind speed of 4 $m \cdot s^{-1}$, temperature difference between the inside and outside air of 30 ℃.
[3]Results measured at low wind speed of 1.6 $m \cdot s^{-1}$ and at high wind speed of 5.1 $m \cdot s^{-1}$, temperature difference between the inside and outside air of 10∼45 ℃.
[4]Results measured at wind speed of 0.9∼7.1 $m \cdot s^{-1}$.
[5]Results measured at low wind speed of less than 2 $m \cdot s^{-1}$ and at high wind speed of more than 2 $m \cdot s^{-1}$.

confirmed that the overall heat transfer performance of covering material coupled with thermal screen could be measured quantitatively by using hot box. If the hot box available for laboratory use is developed by using the technique obtained from this study, it will be possible to compare the insulation efficiencies of greenhouse covering materials and thermal screens commonly used in the country.

Table 2 shows the comparison of overall heat transfer coefficients of polyethylene film between existing research results and present study. Seginer et al. (1988) carried out experiment in a small experimental greenhouse with a dry convective heat source in it but without crop. The wind speed limited to less than 2.5 $m \cdot s^{-1}$. Covering material used was polyethylene plastic film of 0.1 mm thick sheets. The inside temperature range was between 10.3∼37.4 ℃ and outside temperature range was between 10.5∼24.1 ℃. The average values of our research results at high and low wind were much similar to Seginer's results. Nijskens et al. (1984) evaluated the overall heat transfer coefficients of single and double layers for a series of materials used as greenhouse covers under clear and overcast sky by theoretical analysis. The wind speed was 4 $m \cdot s^{-1}$. The covering used was polyethylene plastic film 0.1 mm thick sheets. Inside temperature was 20 ℃ and outside temperature −10 ℃. The radiative temperature of sky was −28 ℃. Even if the wind speed and temperature difference between the inside and outside air were greater than our research, the coefficients were lower than the present study. Geoola et al. (2009) carried out experiment in a guarded laboratory hot box partially based on ASTM standards C 236 and C 976. Cladding material used was polyethylene plastic film 0.15 mm thickness. Results were measured at low wind speed of 1.6 $m \cdot s^{-1}$ and high wind speed of 5.1 $m \cdot s^{-1}$, temperature difference between the inside and outside air of 10∼45 ℃. There was much difference of coefficient depending on temperature difference between the inside and outside air. The coefficient at low temperature difference was similar to our result. It's necessary to do another experiment in order to compare in more detail. Feuilloley and Issanchou (1996) carried out external experiment by using two isothermal hot boxes. A series of 6 films in wet and dry conditions were tested. All the films were made of low density polyethylene and their thickness was 0.2 mm. Results were measured at wind speed of 0.9∼7.1 $m \cdot s^{-1}$. Outside air temperature was 1.1∼16.0 ℃ and inside temperature of hot box was 13.8∼24.7 ℃. The radiative temperature of sky was between −4.8∼−15.8 ℃. The measured value was slightly greater than the result of our study. Even though this difference was because the environment conditions for experiment were dissimilar each other, it was difficult to find the more exact cause.

IV. CONCLUSIONS

The objective of the present study was to investigate the overall heat transfer coefficient of greenhouse covering materials with or without thermal screens commonly used in the country under external conditions by using the hot box method. The hot box was designed, built, and exposed to external weather conditions to determine the overall heat transfer coefficient of different plastic film with or without thermal screens depending on shelter. The experiment was made on the test conditions of eight treatments combined covering materials and thermal screens with and without shelter from the sky radiation in dry condition. It was found that the inside temperature of the hot box was well controlled and stable around the predetermined setting temperature according to the energy supplied. When we measure the overall heat transfer coefficients in a laboratory, it is necessary to establish the measuring system to be able to simulate the sky radiation. The insulation effect of greenhouse could be acquired by reducing the heat loss through blocking sky radiation. The overall heat transfer coefficients measured at high wind speed were greater than the coefficients at low wind speed. If the hot box available for laboratory use is developed by using the technique obtained from this study, it will be possible to compare the insulation performance of greenhouse covering materials and thermal screens commonly used in the country quantitatively. The overall heat transfer coefficients of our research results were much similar to Seginer's research results.

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REFERENCES

1. Abdel-Ghany, A. M., 2011. Solar energy conversions in the greenhouses. Sustainable *Cities and Society* 1: 219-226.
2. Asdrubali, F., and G. Baldinelli, 2011. Thermal transmittance measurements with the hot box method: Calibration, experimental procedures, and uncertainty analyses of three different approaches. *Energy and buildings* 43: 1618-1626.
3. ASTM, 1993. Standard test method for steady-state thermal performance of building assemblies by means of a guarded hot box. *ASTM standards C* 236-89: 52-62.
4. Feuilloley, P., and G. Issanchou, 1996. Greenhouse covering materials measurement and modelling of thermal properties using the hot box method, and condensation effects. *J. Agri. Engng Res.* 65: 129-142.
5. Geoola, F., Y. Kashti, A. Levi, and R. Brickman, 2009. A study of the overall heat transfer coefficient of greenhouse cladding materials with thermal screen using the hot box method. *Polymer Testing* 28: 470-474.
6. Giacomelli, G. A., and W.J. Roberts, 1993. Greenhouse covering systems. *HortTechnology* 3(1): 50-58.
7. Kittas, C., 1994. Determination du coefficient global de transmission de chaleur à travers la paroi d'une serre. [Overall heat transfer coefficient of the greenhouse cover]. *Agricultural and Meteorolgy* 69: 205-221.
8. Nijskens, J., J. Deltour, S. Coutisse, and A. Nisen, 1984. Heat transfer through covering materials of greenhouses. *Agricultural and Forest Meteorology* 33: 193-214.
9. Ozturk. H. H., 2005. Experimental determination of the overall heat loss coefficient for energy requirement of greenhouse heating. *Int. J. Energy Res.* 29: 937-944.
10. Papadakis, G., D. Briassoulis, G. S. Mugnozza, G. Vox, P. Feuilloley, and J. A. Stoffers, 2000. Radiometric and thermal properties of, and testing methods for, greenhouse covering materials. *J. Agric. Engng. Res.* 77(1): 7-38.
11. Pirard, G., J. Deltour, and J. Nijskens, 1994. Controlled operation of thermal screens in greenhouses. *Plasticulture* 94(3): 11-22.
12. Plaisier, H., 1996. The use of thermal screens in greenhouses in mild climates. *Plasticulture* 96(3): 43-48.
13. Seginer, I., D. Kantz, U. M. Peiper, and N. Levav, 1988. Transfer coefficients of several polyethylene greenhouse covers. *J. Agric. Engng Res.* 39: 19-37.
14. Zabeltitz, C., 1992. Energy-efficient greenhouse designs for Mediterranean countries. *Plasticulture* 94(4): 43-48.