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Improving Greenhouse Insulation through Multilayer Thermal Screens Using the Hot Box Method

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Abstract - The overall heat transfer coefficient of thermal screens is evaluated. Such screens are applied to improve the performance of combined heating/cooling and dehumidification system, invented by Avraham Arbel and mutually developed with DryGair Energies Ltd., providing the desired conditions in closed greenhouse. By significantly reducing fossil energy consumption, this design contributes to sustainability as well. Reduction of heat loss or gain is achieved by using several layers of thermal screens. In this work, a hot box methodology to measure heat flux through multi-layers insulation materials is implemented, while considering different types of thermal screens and their integration with greenhouse covers to estimate the overall heat transfer coefficient. The results indicate that with only one layer, the heat transfer coefficient is reduced by around 70% compared to covers without screens, while the contribution of additional layers may increase the performance to about 90%.

Keywords**:** Heat losses, Hot box experiments, Thermal screens, Multi-layers screens, Greenhouse insulation.

1. Introduction

With high fuel prices, the cost of greenhouses heating has become a major component of expenses and as a result, greatly reduces the profitability. This trend is reflected by the long-term status of the global energy resources on the one hand, and the growing awareness of environmental pollution and global warming problems, on the other hand. Improvement of greenhouse insulation can be achieved by a combination of multi-layer coverage and thermal screens - methods that were developed and tested mainly in the 1970s. However, due to significant drop in fuel prices later on, the implementation of such designs has gradually eliminated. Moreover, lack of awareness for use of low-grade fuel that cause environmental pollution, which contributed to outbreak development of diseases due to high humidity. To remove the excessive humidity, ventilation of the greenhouse was increased, and as a result, fuel consumption was also increased, striking cost effectiveness.

Desired climate conditions are expressed in terms of thermal radiation, leaf temperature, plant transpiration, level of CO_2 and dry foliage ([1] and [2]). Temperature and air humidity control in the greenhouse are required to ensure foliage temperature and transpiration rates at desired levels on one hand, and for the sake of plant health maintain foliage to be dry, on the other hand [3]. For example, in most greenhouses, the acceptable foliage temperature is about 18°C and the transpiration is about 40 gr/m^2 per hour. The basic assumption of most studies considered humidity control greenhouse is that drying systems should not be used ([2] and [4]). Therefore, temperature control and air humidity in the greenhouse are obtained as a result of a combination of heating and ventilation. However, the considerations of the control process need to be extended, including the growth processes [5] and the economic effect.

As a background, [6] has developed a patented DryGair system, which preserves dry foliage and provides the desired temperature and humidity in the greenhouse, by condensing the water vapor during heating hours. In this way, enhanced diseases and moisture are avoided. In addition, this system eliminates vapor condensation on the cover material such that there is no need to ventilate the greenhouse in order to remove the excess humidity, saving extra costs. This approach was tested in practice [1], and proved to be cost effective.

This work focuses on improving the insulation of the greenhouse cover in order to minimize the heating energy consumption ([7], [8], [9], and [10]). Insulation of the greenhouse may be obtained through various combinations of multi-layer covers and thermal screens. For example, adding the thermal screen reduces the heat transfer coefficient in the range from 38% up to 60% ([11], [12], [13], and [14]) for transparent and reflective sheets, respectively. This means that the heat loss transmitted through the thermal screens can be reduced by 80-90% using the materials available today. To prevent thermal radiation, the priority is for covers having high reflection coefficient. Therefore, some cover materials contain IR additives that partially absorb the thermal radiation. Recently, glass [15] covers with higher transition properties have been developed, and accordingly, the resistance to sunlight penetrating is significantly reduced. Multilayered thermal screens cause shading stripes, therefore, their use can be effective during times when there is no sun, including night time, as well as it may contribute to insulation of the greenhouse during extra heating hours in the afternoon.

2. Description of Hot Boxes and Methodology

The technique is based on measurements of the overall heat transfer coefficient of several layers of insulation materials, or samples, to be used as thermal screens in greenhouse. Insulated hot boxes are used for the measurements while different combinations of samples are integrated to the upper surface of the box. The hot box bottom plate is subjected to Joule heating with the power of Q (W). Assuming that the system is in thermal equilibrium (steady state), the overall heat transfer coefficient U (W/m^2C) samples, is given by:

$$U = (\mathrm{Q} - \mathrm{Q}_l)/\mathrm{S}(\mathrm{T}_{in} - \mathrm{T}_{out}) \tag{1}$$

where T_{in} (ºC) and T_{out} (ºC) are the air temperatures inside and outside of the hot box, respectively. S (m^2) is the sample area, aligned with the heat flow direction and Q_l (W) represents side walls heat losses.

In order to increase accuracy, two similar boxes are used with dimensions shown in Figure 1a. The boxes are built in a way that the inside dimensions are 1m×1m×1.3m (length×width×height), including layers set of 0.3m height. The side walls of the boxes consist of polyurethane foam panel of 0.1m thick coated by thick wood covers for structural stiffness and additional insulation. The upper surface includes a window, where polyurethane frames with material samples could be inserted. The frames are squares with an inner dimension of 1m and an outer dimension of 1.2m. The thickness is 10cm (similar to the box) and the height is 5cm. It is possible to install up to six frames in different material combination between the samples with 5cm distance.

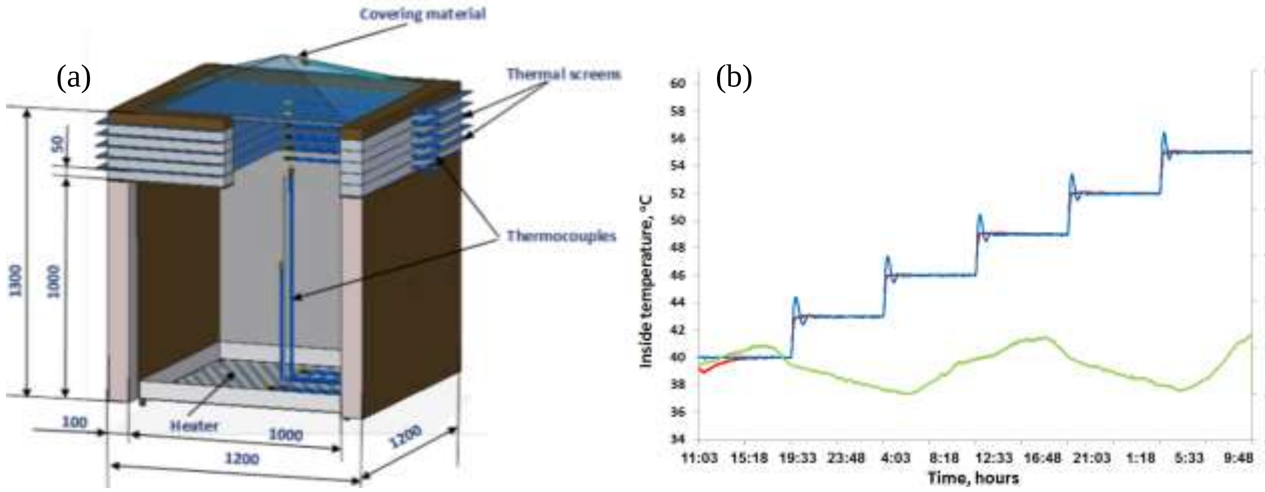

Fig. 1: (a) Schematic view and dimensions of the hot box; b) Typical test results: red line -T_{in}, temperature in the first box with IR cover and three IC-100 thermal screens; blue line- T_{in}, temperature in the second box with IR cover and one Fo-Al thermal screen; green line- T_{out} , outside(room) dry temperature.

The covering material (different polyethylene films or glass) is adjusted into the upper wooden frame. These frames are fastened to the box by springs located in the four corners and anchored to the base of the box for easier reinstallation. The lower internal iron plate is heated by multi-pass s-shape flexible heating wire in order to provide uniform heat flux through the $1m^2$ surface. A variable power transformer (24 Watt) regulated the power of the heater by changing the voltage using stepper motor controlled by programmed data-logger. The measurements were managed by a cellular application. Such arrangement enabled incremental change of power with high accuracy. Thermocouples were installed at at the heated bottom plate, and inside the air layer between each sample. The inside temperature was measured by a thermocouple located in the center of the box internal volume, while the external conditions were recorded using a meteorological station. The boxes were located inside the laboratory room in order to provide steady ambient conditions.

In order to calculate the heat losses through the side walls, the upper frame was replace by a 0.1m thick polyurethane plate on the top of the each box and the internal and external temperature of the side boxes were measured. The heat losses were measured in a series of five experiments during the whole period of the tests and were in order of 0.4W/m^2 in average for each box.

Under the conditions of each test, the measurements were carried out over two days. The initial inside temperature was 40ºC and was increased in steps of 3 degrees up to 55ºC. It was found that in this range the measurements were stable. Since the measurements of the overall heat transfer coefficient require equilibrium, the boxes were heated for eight hours for each temperature. The measurements was scanned every second and averaged over every 1 minute via data-logger. The typical temperature reading is shown on Figure 1b. It can be seen, that the temperature stabilizes in a short time. These results were obtained when the both boxes were covered by materials contain IR additives, while three IC-100 thermal screens were added in one box, and one screen with foil aluminium coating was added in the other box. For note, IC-100 screens are thermal-reflective meshed screens made of high-density polyethylene fiber with built-in aluminium coated strips. Only the measurements taken during the last two hours over specific temperature are used in the calculations of heat transfer coefficient. The precision of the temperature measurements is about 0.05ºC and it is due to time averaging and thermocouple precision.

3. Results

The typical overall heat transfer coefficients as a function of thermal screens number are presented in Figure 2. The presented results correspond to experiments with IR cover and added thermal screens of type IC-100, IC-30, IC-0, with shading factors 98-99%, 30-35% and "clear", respectively. There are energy-savings screens, commonly used in close greenhouses to provide stable climatic conditions during the day. The values of heat transfer coefficient for different number of thermal screen are normalized by the value measured using one covering material (U = 7.33W/m^{2}C, σ = 0.47).

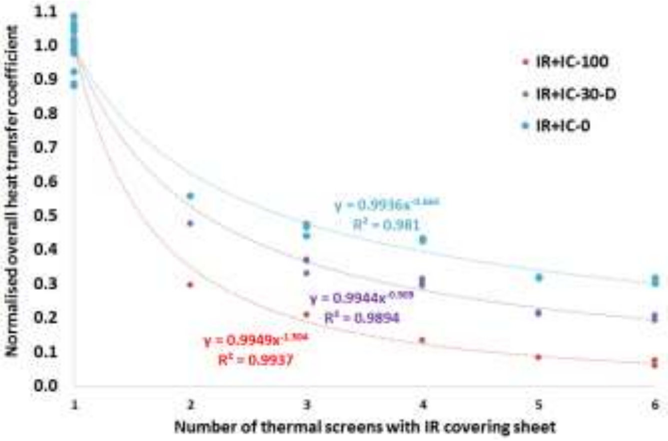

Fig. 2: Normalised overall heat transfer coefficient for IR cover and three types of thermal screens.

It is shown that the normalized heat transfer coefficient decreases rapidly for all three screen types, showing a very good agreement of the power trend line with an R-square value close to unity. It is also seen that for IC-100 containing maximum amount aluminium strips, the reduction of overall heat coefficient can reach 70%. With following addition of screes the coefficient decreases by 10% approximately. Finally, it can be reduced by 90% by using five layers of screens. It is also shown that using of four IC-30 screens can reduce the coefficient by 70%, while using IC-0 can reduce the coefficient from 50% up to 70% in total.

4. Conclusion

The multi-layer thermal screens technology could be further extended to provide improved greenhouse insulation. Use of the screens can reduce the overall heat coefficient from 70% (for one layer) up to 90% (for multi-layer screens), thus reducing energy consumption in the greenhouse, accompanied with smaller environmental impact, as well as providing optimal breeding conditions. In addition, the proposed design suggest a reduction in diseases, an increase in yield and an improvement in the quality of the product.

References

[1] C. Stanghellini, "Transpiration of greenhouse crops and aid to climate management," Ph.D. Disseration, Agricultural University, Wageningen, The Netherlands, 1987.

[2] O. Jolliet, "HORTITRANS, a model for prediction and optimizing humidity transpiration in greenhouses," *Journal of Agricultural Engineering Research*, vol. 57, pp. 23-37, 1994.

[3] Y.Elad and H. Yunis, "Effect of microclimate and nutrients on development of cucumber gray mold (Botrytis cinerea)," *Phytoparasitica*, vol. 21, no. 3, pp. 257-268, 1993.

[4] C. W. Stanghellini and Th. M. Meurs, "Environmental control of greenhouse crop transpiration," *Journal of Agricultural Engineering Research*, vol. 51, pp. 297-311, 1992.

[5] M. Trigui, L. Gaurent and S. Barrington, "Measuring and modeling greenhouse mass balances," An ASAE/CSAE MEETING PRESENTATION, Paper No. 93-4041, 1993

[6] A. Arbel, M. Barak, and A. Shklyar, "Method and system for heating and dehumidifying," International Application No. PCT/IL2008/001449, 2008.

[7] A. Arbel, M. Barak, A. Shklyar, G. Lidor, Y. Elad, M. Sofer, H. Yehezkely, D. Shmueli, A.Slepoy and L.Ganot, "Performance of combined heating and dehumidification system for greenhouses," *Acta Hort*., vol. 952, pp. 449-456, 2012.

[8] N. E. Andersson, and O.F. Nielsen, "Energy consumption, light distribution and plant growth in greenhouse partly insulated with non-transparent material," *Gartenbauwissenschaft*, vol. 65, pp. 190-194, 2000.

[9] G. P. A. Bot, "Developments in indoor sustainable plant production with emphasis on energy saving," *Comput. Electron. Agr.*, vol. 30, pp. 151-165, 2001.

[10] J. Villeneuve, D. de Halleux, A. Gosselin and D. Amar, "Concept of dynamic liquid foam insulation for greenhouse insulation and the assessment of its energy consumption and agronomic performances," *Acta Hort*., vol. 691, pp. 605-610, 2005.

[11] B. J. Bailey, "Thermal screens for reducing heat losses from glasshouses," *Acta Hort.* (ISHS), vol. 70, pp. 26-34, 1977.

[12] B. J. Bailey, "Control strategies to enhance the performance of greenhouse thermal screens," *J. Agric. Engin. Res*., vol. 40, pp. 187-198, 1988.

[13] F. Geoola, Y.Kashti, A. Levi and R. Brickman, "A study of the overall heat transfer coefficient of greenhouse cladding materials with thermal screens using the hot box method," *Polymer Testing*, vol. 28, pp. 470–474, 2009.

[14] J. Meyer, "Energy saving with mobile thermal screens," *Acta Hort*. (ISHS), vol. 115, pp. 677-684, 1981.

[15] S. Hemming, F. Kempkes and V. Mohammadkhani, "New glass coatings for high insulating greenhouses without light losses - energy saving, crop production and economic potentials," *Acta Hort*, vol. 893, pp. 217-226, 2011.