Heat radiation phenomena from a greenhouse crop canopy at night: 1. The curtain effect in a greenhouse covered with transparent material

M. G. Amsen
Government Glasshouse Crops Research
Kirstinebjergvej 10, 5792 Årslev, Denmark

Resumé

Varmestråling fra en plantebestand i væksthus om natten.

1. Gardineffekten i et væksthus dækket med transparent materiale.

Anvendelse af gardiner om natten har en varmebesparende effekt. Med hensyn til strålingstab har man indtil nu anvendt ret enkle modeller, som bygger på den antagelse, at væksthuset er dækket med et materiale, der strålingsmæssigt opfører sig som et sort legeme ($e = 1$).

Dette er imidlertid ikke rigtigt. Selv om glassets transmission overfor langbølget stråling er meget lille ($t_h = 0{,}05$), er det dog en faktor, man ikke kan se bort fra. Desuden bygges, især i udlandet, væksthuse af andre materialer, som gennemgående har en mere udpræget transmission overfor langbølget stråling.

Formålet med denne artikel har derfor været at gøre rede for hvordan sådanne forhold vil påvirke netto-strålingstabet fra en plantebestand.

Som det fremgår af fig. 1 er den relative besparelse, der opnås ved at anvende et gardin i et væksthus dækket med transparent materiale, større jo større husets transmissionsevne (t_h) er.

Abstract

In previous papers the author introduced a curtain factor which enables engineers and growers to make a qualified distinction between materials which may be used for heat saving purposes in greenhouse production (*Amsen,* 1974).

This curtain effect was based on the assumption that the greenhouse cover (e.g.glass) acted as a black body ($e = 1$) in respect to emitted radiation.

This, of course, is neither true nor satisfying. Greenhouses are built not only of glass, but also of materials which have a more pronounced transmissivity to long wave radiation.

In those cases the curtain effect may be extended to comprise the transmissivity of the greenhouse cover (t_h) and the curtain effect according to:

$$C_{s,h} = \frac{1 + t_h}{2\,\dfrac{1+c_s}{1-c_s} + 1 + t_h}$$

Introduction

In previous papers (*Amsen* 1973, 1974, 1975,a,b,) dealing with the greenhouse and curtain effect, the author made the assumption that the glasshouse cover acted as a black body ($e = 1$).

This, of course, is neither true nor satisfying. Furthermore, greenhouses are covered with other material than glass. Those materials may have a more pronounced transmissivity to long wave radiation ($t > 0$).

It may, therefore, be feasible to introduce an extended model which takes those abilities into account. A model which is valid for greenhouses others than those made of glass but covered with a material which is more transmittent to long wave radiation.

The author is fully aware of the fact, that more sophisticated work has been done in the field of the radiant abilities of thin plastic film (*Tien et al.*, 1972). Also, that a more precise model should take into account the effect of the angle factor between the different radiating surfaces (*Kanthak*, 1970, *MxAdam et al.*, 1971). On the other hand, valuable information can be obtained, or reliable comparisons can be made with the help of less expensive methods (*Kohlmeier*, 1975, *Amsen* 1975 b). From this it may be evident, that there still may be a need for rather crude models similar to those published by the author so far.

In accordance with this, it is important to notice that the heat loss is related to the temperature of the exposed plant tissues instead of the temperature of the inside air as is done in the traditional approach (*Bailey & Winspear*, 1975, *Tantau*, 1975).

Statements and definitions

Transfer of heat by radiation may be expressed in either heat flux (watt) or heat flux density (watt/m^2).

In previous papers the author (*Amsen*, 1973, 1974, 1975 a, 1975 b) made the assumption that the involved surfaces (plant canopy, curtain, glasshouse cover and atmosphere) behaved as plane parallel surfaces. In accordance with this, the heat transfer was expressed in heat flux densities (watt/m^2).

In a more precise approach it will be preferable to express heat transfer in units of a heat flux (watt), so that the configuration factors (*McAdam et al.*, 1971) may be taken into account.

This will, of course, not influence the evaluation of the curtain factor and the curtain effect published in the papers mentioned before.

1. The radiant heat flux

To examine the simultaneous effect of the greenhouse cover and the curtain on the radiant net heat flux from the plant canopy, it is necessary to look upon the six surfaces involved and the corresponding emitted radiation, namely:

1. The upper surface of the plant canopy (H_p).
2. The lower surface of the curtain (H_s).
3. The upper surface of the curtain (H_s).
4. The lower surface of the greenhouse cover (H_h).
5. The upper surface of the greenhouse cover (H_h).
6. The lower surface of the atmosphere (H_a).

The problem will be treated according to a two screen model, where radiation is the only form for heat exchange. In other words, the greenhouse is assumed to be closed and the effect of convection is not taken into account.

The curtain is assumed to cover the plant canopy totally. Its radiant properties are expressed by its transmissivity (t_s) and its reflectivity (r_s) provided $e_s = 1 - t_s - r_s$. These properties can be expressed in a curtain factor: $c_s = t_s - r_s$ and according to this $-1 < c_s < 1$. The greenhouse cover is assumed to have a transmissivity (t_h) according to $e_h = 1 - t_h$.

The derivation of the extended curtain factor

The net radiant heat flux from the plant canopy can be expressed by:

$$dH_p = H_p - H_s - r_sH_p - t_sH_h - t_st_hH_a \qquad (1)$$

The last three terms indicate the amount of heat reflected (r_sH_p) and transmitted (t_sH_h) by the curtain and the amount transmitted by the curtain and the greenhouse cover ($t_st_hH_a$).

The radiant heat flux emitted from the curtain to one side (H_s) will be equal to half of the total amount received, according to:

$$H_s = \frac{1-t_s-r_s}{2} (H_p + H_h + t_hH_a) \qquad (2)$$

After eliminating this value in equation (1):

$$dH_p = \frac{1+t_s-r_s}{2} (H_p - H_h - t_hH_a) \qquad (3)$$

This shows that the radiant net heat flux (dH_p) not only strongly depends on the radiant properties (t_s and r_s) of the curtain, but also on the transmissivity of the greenhouse cover (t_h).

The radiant heat flux from the greenhouse cover (H_h) will in the same way be equal to half of the total amount received, according to:

$$H_h = \frac{1-t_h}{2}(t_sH_p + H_s + r_sH_h + r_st_hH_a + H_a) \qquad (4)$$

An expression of the net radiant heat flux from the plant canopy, consisting of the radiant heat flux from the plant canopy (H_p) and the atmosphere (H_a) only, may be obtained by combination of equations (3) and (4):

$$dH_p = \frac{(1+t_s-r_s)(1+t_h)}{3+t_s-r_s+th\,(1-t_s+r_s)}(H_p - H_a) \qquad (5)$$

By inserting the curtain factor ($c_s = t_s - r_s$) defined by the author previously, equation (5) may be simplified to:

$$dH_p = \frac{(1+c_s)(1+t_h)}{3+c_s+t_h(1-c_s)}\,dH_o \qquad (6)$$

As can be seen from equation (6), high transparent properties of the greenhouse cover will increase the net radiant heat flux from the plant canopy.

For values of t_h equal to zero, equation (6) will be identical to the exchange factor published by the author previously (*Amsen,* 1974).

The extended curtain effect

The curtain effect previously defined by the author (*Amsen,* 1974) may now be extended to take into account the effect of the transmissivity of the greenhouse cover and the curtain factor of the curtain as well as:

»The relative difference in net heat radiation from a plant canopy in a greenhouse, with a transmissivity (t_h) before and after a curtain with a curtain factor ($c_s = t_s - r_s$), is placed in the greenhouse«.

Mathematically:

$$C_{h,s} = \frac{1+t_h}{2\frac{1+c_s}{1-c_s} + 1+t_h} = \frac{1-c_s}{2\frac{1+c_s}{1+t_h} + 1-c_s} \qquad (7)$$

For a greenhouse cover which acts as a black body (e = 1) equation (7) will be identical with the curtain effect defined previously (*Amsen,* 1974):

$$C = \frac{1-c_s}{3+c_s},\ (t_h = 0) \qquad (8)$$

The curtain effect ranges, depending on the radiant properties of the curtain and the greenhouse cover, between zero for a fully transparent cover and curtain ($c_s=t_h=1$) to one for a fully reflecting curtain ($c_s= -1$).

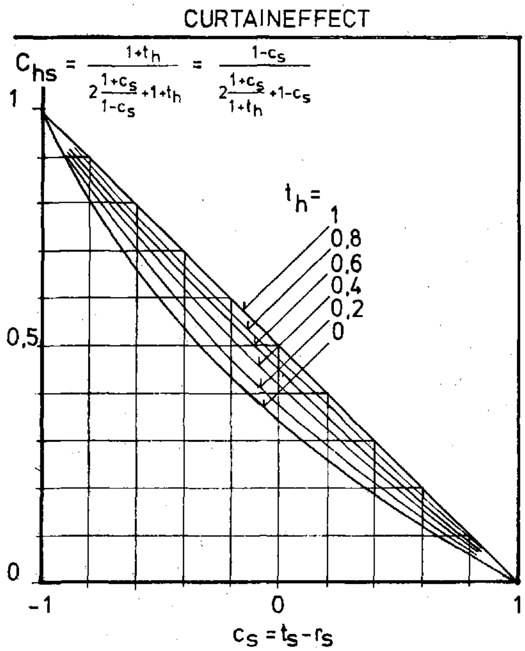

Fig. 1. The curtain effect as a function of different radiant properties of the curtain, expressed by the curtain factor $c_s = t_s - r_s$, for different transmissivity of the greenhouse cover (t_h).

Gardineffekten som funktion af strålingsegenskaber af gardinet, udtrykt ved gardinets gardin faktor, $c_s=t_s-r_s$, ved forskellig transmissionsevne af væksthusets beklædning.

Estimation of the curtain factor

The curtain effect of a material may be estimated in a very simple way by applying an insulated box filled with sand, which is kept at a distinct temperature with an electric heating coil and thermostate (*Amsen,* 1975b).

The box is covered with glass and placed in a refrigerating room at constant temperature.

From the difference in heat consumption between the box covered with glass and covered with glass and the material to be investigated, the curtain effect (C) can be calculated.

From this value the curtain factor (c_s) of the material in question can be calculated according to:

$$c_s = \frac{1+t_h-(3+t_h)C}{1+t_h+(1-t_h)C}$$

Table 1. The curtain effect and the curtain factor of different materials.

	c_s	C, %
Brown wrapping paper	0,038	32,7
(brunt karduspapir)		
Shading curtains		
(skyggegardiner)		
Leavil 50/59	–0,032	35,9
»Reflection«	0,014	33,8
Foil for short day treatment		
(gardiner til mørklægning)		
»Silver vinyl«	–0,030	49,2
0,08 mm black plastic foil	0,039	36,2
(sort plastic folie)		
Polyethylene foil		
(polyethylen folie)		
0,03 mm colourless	0,29	22,6
(farveløs)		
0,03 mm white	0,38	19,2
(mælkehvidt)		
Aluminium foil		
(aluminiumsfolie)		
Aluminium foil	–0,73	77,2
(aluminiumsfolie)		
Aluminium varnished	–0,73	77,1
(aluminium, lakeret)		
Aluminium coated with plastic films	–0,30	49,3
(aluminium belagt m. plastfolie)		
Insulating material		
(isolationsmateriale)		
25 mm styropor	–0,85	86,7

Table 1 shows the curtain effect (C) and the curtain factor (c_s) for some materials which may be of interest for reducing radiant heat loss in greenhouses. The value of the glass is set to t_h = 0,05.

List of symbols:
(Liste over symboler)

H radiant heat flux, watt
(varmestråling, watt)

C curtain effect
(gardineffekt)

c_s curtain factor
(gardinfaktor)

subscripts
(notation)

$\cdot_p$ plant canopy
(plantebestand)

$\cdot_s$ curtain
(gardin)

$\cdot_h$ greenhouse cover
(væksthusbeklædning)

$\cdot_a$ atmosphere
(atmosfære)

Acknowledgments

The author wishes to express his thanks to P. E. Hansen, Mathematical Department, and K. Høgh Schmidt, Physical Department of the Royal Veterinary and Agricultural University in Copenhagen, for helpful discussions during preparration of the text of this paper.

Literature

Amsen, M. G., 1973. Heat radiation phenomena from a glasshouse crop canopy at night. Acta Hort. 46:139-145.

Amsen, M. G., 1974. Heat radiation phenomena from a glasshouse crop canopy at night. II. A mathematical evaluation of the curtain effect. Phytotronic III (in press).

Amsen, M. G., 1975a. Heat radiation phenomena from a glasshouse crop canopy at night. III. The influence of convective sensible heat transfer on the greenhouse – and curtain effect. Acta Hort. 51:29-35.

Amsen, M. G., 1975b. Heat radiation phenomena from a glasshouse crop canopy at night. IV. Determination of the curtain factor by a simple method. Royal Veterinary and Agricultural University, Copenhagen. Yearbook 1976:101-111.

Bailey, B. J. and *K. W. Winspear,* 1973. Reducing the heat requirements of a glasshouse. Acta Hort. 51:19-28.

Kanthak, P., 1970. Der Einfluss von Heizungssystemen mit unterschiedlichem Strahlungsanteil auf das Klima und den Wärmehaushalt von Hallenbauten mit grossen Glassflächen, speziell von Gewächshausern. Fortschrift Bericht der V.D.I.-Z. Reihe 6, Nr. 28.

Kohlmeier, D., 1975. Modellmessungen zur Beureilung vom Wärmedämmungsmasshahmen (II). Rheinische Monatsschrift 75 (11):379.

McAdam, D. W., A. K. Khatry, M. Iqbal, 1971. Configuration factors for greenhouses. Transactions of the ASAE 1971:1068-1072.

Tantau, H. J., 1974. Heizungssysteme im Gewächshaus. Institut für Technik in Gartenbau und Landwirtschaft. Technische Universität, Hannover, Heft 1.

Tien, C. L., C. K. Chan, G. R. Cunnington, 1972. Infrared radiation of thin plastic films. Journal of Heat Transfer:41-45.

Manuskript modtaget den 29. november 1976.