HEATING LOAD OF A GLASSHOUSE FROM THE PHYSICAL POINT OF VIEW

G.P.A. Bot
Dept. of Physics and Meteorology
Agricultural University
Wageningen, The netherlands

Abstract

The heating load of a greenhouse depends considerable on a number of environmental conditions. Regarding the energy balance over the entire greenhouse, the heat consumption represents the net energy flow from the greenhouse to the environment under steady state condition. Due to the inherent fluctuations in the magnitude of the various environmental factors, the heat consumption will also vary. When the heat consumption is related to the temperature difference between the in-and the outdoors air respectively, a functional dependence exhibiting fluctuations within the broad margins ascribed to the anple and continuous environmental changes has been found. Analysis of each particular situation indicates that the majority of the environmental factors produce an offset to the heat consumption (thus for each temperature difference between the in- and outdoors the in- or decrease in heat consumption is the same). Moreover it is solely the wind velocity that affects the slope of the line representing the heat consumption plotted versus the temperature difference. This is of particular importance in current efforts aimed to have "more profitable use of energy in protected cultivation". Since just these slope variations are relevant in predicting the amount of energy that could be saved by a one degree temperature reduction in the greenhouse. Like wise the slope can be interpreted as the amount of energy required to increase the greenhouse temperature by one degree. Such figure is of crucial importance in the optimization studies.

Introduction

The heating load or heat consumption of a greenhouse has to quantify how much heat has to be added to the greenhouse system as a funtion of the environmental conditions and the temperature difference between the in- and outside air.
In literature the following empirical formula are used in which the heatingload coefficient k is defined:

$$Q'' = k.\ (T_i - T_o) \qquad \text{(Horiguchi, 1978)}$$

and

$$Q'' = k.A'.(T_i - T_o) - c.R_s \qquad \text{(Schockert et al., 1979)}$$

in which

Q'' is the heat demand per unit floor area
A' is the normalised area of outside cover
R_s is solar insolation
and c a coefficient defining what part of solar insolation as a mean value is utilised for heting (for the Dutch situation c has a value of about 1/3).

The advantage of this definitions of k is its simplicity. When the user is only interested in the behaviour of the greenhouse system over a longer period and not on a certain moment, these definitions of k can be sufficient to calculate for instance the power of the heating system in different situations. The disadvantage however is that it is not, like any empirical model, able to predict the heat consumption on a certain moment in a very particular situation. For some applications however, we are not only interested in the mean behaviour of the system, but especially in the response in time from situation to situation. Especially in optimization studies (Challa et al.,1979, Seginer,1979)this is of special interest. Of course an extensive description of the physical processes in the greenhouse, as is given in model studies (Bot,1979), can probably give the answer, but then the complexity is a disadvantage. In the following we will try to combine the simple definition of a heating load coefficient k with a physical description to find a definition which is both simple and predictive in optimization studies.

2. Heat balance

To describe how the heat, supplied by the heating system, is flowing from the greenhouse to the outside environment, we can consider the greenhouse as a black box and set up the heat balance over this black box. So in this case we are not interested in heat fluxes inside the greenhouse, the only interest is how heat flows into and out the greenhouse and how this is dependent on environmental conditions. The ingoing heat fluxes per unit floor area are (fig. 1):

a) the total heat Q" supplied by the heating system

b) the total absorbed short wave radiation S_a, which is the difference between the global radiation S_g and the reflected radiation S_r.

c) the absorbed long wave radiation L_s, emitted by the sky with effective sky temperature T_s

The outgoiing heat fluxes are (also per unit area):

a) the long wave radiation L_c emitted by the cover with temperature T_c

b) the convective heat H_c lost from the cover to the outside air with temperature T_o

c) the sum of sensible and latent heat H_v lost trough the cover by ventilation from the inside to the outside air with temperatures T_i and T_o respectively.

The heat balance over the greenhouse system is the sum of the above stated fluxes with positive or negative sign as indicated by the direction of the representing arrows in fig. 1:

$$Q''+S_a+L_s-L_c-H_c-H_v=0$$

In this balance heat storage is neglected,so it is only allowed for steady state situations. For our application however this is not important,as we will see in chapter 3.

3. Influence of environmental factors

The heating load is the sum of the in- and outgoing heatfluxes as stated in the heat balance:

$$Q''=H_v+H_c+L_c-L_s-S_a$$

To define how the heating load is dependent on the environmental factors we can determine that influence on the in- and outgoing heat fluxes. For a good understanding we will start with a very simple, imaginairy, situation: let us define a neutral situation, in which no short nor long wave radiation occurs.The heating load in this situation is only consisting of convection from the cover and ventilation through the cover.

For the convective flux H_c we can state that

$$H_c = k_c \cdot (T_c - T_o)$$

which is a common definition for a heat transfer coefficient k.
For convective processes the transfer coefficient is a function of some physical properties of the flowing medium (outside air), for forced convection on the velocity of the flowing medium (outside wind speed), and for natural convection on the temperature difference between the wall and the flowing medium (temperature difference between the cover and the outside air). In almost all situations natural convection from the cover to the outside air can be neglected. So k_c is only a function of outside wind speed u:

$$k_c = k_c(u)$$

Because of the fact that the heating load has to be related to the temperature difference between the in- and outside air, the temperature of the cover has to be translated into the inside air temperature T_i.
The temperature of the cover can be found from the complete heat balance over the cover, in which convective heat transfer to the inside and outside air and radiative heat transfer to the crop and soil and to the sky have to be incorporated. The radiative transfer being an independent variable, we can state that the cover temperature for our purpose can be considered as a function of in- and outside air temperatures and the convective transfer to in- and outside air. With the transfer to the inside air being constant, and the transfer to the outside air varying with wind velocity, the result is:

$$T_c = T_i - f(u) . (T_i - T_o)$$

Substituting this in H_c:

$$H_c = k'_c(u) . (T_i - T_o)$$

with

$$k'_c(u) = k_c(u) (1 - f(u))$$

For the total heat flux by ventilation we can state that:

$$H_v = {}_v (c_p (T_i - T_o) + r \ (e_i - e_o))$$

in which

$_v$ is the amount of exchanged air by ventilation
c_p is the specific heat of air per unit volume
r is the heat of evaporation
and e_i, e_o the water vapor concentration respectively inside and out

For an empty greenhouse there is only sensible heat transport, with a crop inside latent heat is important too. Due to the coupling of heat and water vapor balances inside the greenhouse, there is a mutual influence between the inside temperature and the water vapor concentration. No simple relation can be stated between this fysical quantities. We will define the influence of ventilated sensible heat on the heat consumption first. The part of sensible heat will cause unaccuracy in this approach, dependent on its part of the total. In winter period, in which we apply the heating load coefficient, this part in general is small, espiacially when artificial heating is supplied.
The amount of exchanged air, causing ventilated sensible heat, is a function of outside wind speed as mean parameter (Bot, 1979, Kozai et al., 1979). So the heat loss by ventilation can be represented by:

$$H_v = k_v(u) \ (T_i - T_o)$$

Adding convective and ventilative heat flows, the heat load in the neutral situation is:

$$Q'' = H_c + H_v = k_{tot}(u) \cdot (T_i - T_o)$$

$$\text{with } k_{tot}(u) = k_c'(u) + k_v(u)$$

Representing the heating load as a function of the temperature difference between the in- and outdoors in a graph, this will be a straight line through the zero point (fig. 2). The slope of this line is a function of wind speed only, from which the following important conclusion can be drawn: the amount of extra energy needed to heat up the greenhouse temperature one degree or the energy that can be saved by decreasing the greenhouse temperature one degree as is represented by the slope in the heating line, is only dependent on the outside wind speed, and not on the greenhouse temperature itself (instead of greenhouse temperature the temperature difference between the in- and outdoors can be read in the conclusion).

In the non-neutral situation short and long wave radiation is entering and leaving the greenhouse. The absorbed short wave radiation S_a and the incoming long wave radiation L_s are independent of the greenhouse temperature, causing the same decrease of the heating load for all temperature differences. So the heating line is shifted in a parallel way, and the slope of the line does not change (fig. 3).
The outgoing long wave radiation L_c is dependent on the cover temperature, which is dependent on the inside temperature. The variation of the cover temperature with variations of the inside temperature are small because of the low heat transfer between inside air and cover and the high transfer between cover and outside air. Besides that the dependency of L_c is on the absolute cover temperature. So the dependency of the outgoing long wave radiation on the greenhouse temperature is of second order and can therefore be neglected. So its effect on the heating line is the same as that of the other radiative terms: it causes a shift of the heating line and does not affect the slope of this line.
Because all radiation terms have the same effect on the heating load, they can be added resulting in the net radiation above the greenhouse cover R_n.
A revised version of the heatingload coefficient can now be formulated:

$$Q'' = k_{tot}(u) \cdot (T_i - T_o) - R_n$$

This definition avoids apparent changes in k due to changes in the net radiation, especially in the net radiation regime.
For optimization studies it is important to know that the amount of heat that is needed extra to increase or that can be saved by decreasing the temperature difference between in and outdoors is independent on the temperature difference itself, is independent on the radiation regime and only dependent on the outside wind velocity. The definition is already applied successfully in an optimization study. A report of this study is presented on the 1980 cucumber symposium (Challa et al., 1980).

References

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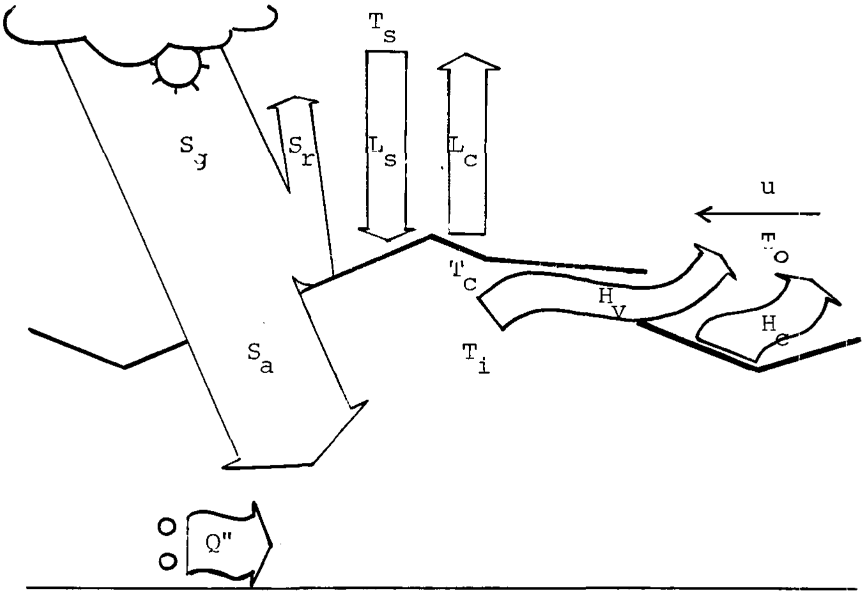

Fig. 1. Heat balance over the greenhouse system.

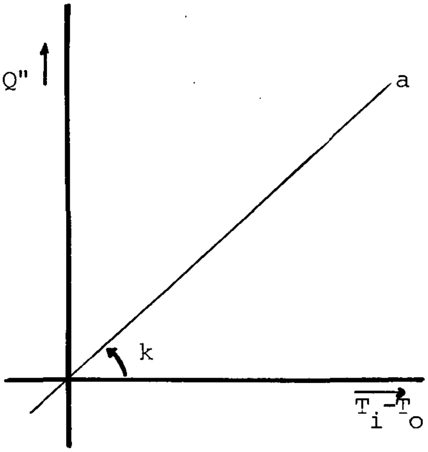

Fig. 2. Heating line for neutral condition.

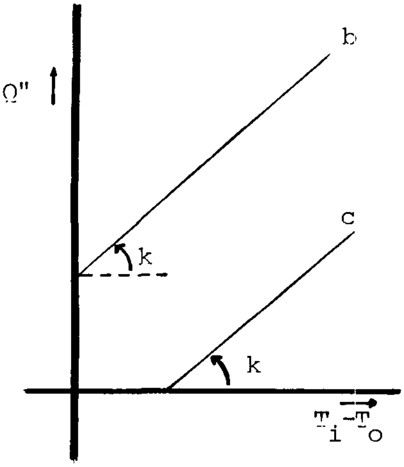

Fig. 3. Heating lines for negative (b), and positive (c) net-radiation.