TEST OF A GREENHOUSE USING LOW TEMPERATURE HEATING

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Abstract

The following results are based on measurements taken between September 1983 and June 1984 :

- an ethylene thermal screen (EVA) and a chrome-coated one (Hecho-therm) showed reductions in the nightly thermal transmittance through the roof of 35 % and 47 % respectively, (52 % if they are used simultaneously).
- below the screens, the leaf temperature of the plant was in average 0.4 K higher than for unscreened plants at the same air temperature
- the influence of the sky temperature is important. It may lead to variations in the heat requirement of more than 50 %
- as wind and sky temperature effects are interdependent a method for evaluating them separately has been found.

1. Introduction

An experiment started in 1982 at the CERN in Geneva with three main objectives :

- to determine whether heating greenhouses using low temperature industrial thermal rejects is feasible and worthwhile from both an agronomic and economic point of view.
- to test different systems that reduce heating costs in greenhouses by maximizing the solar energy contribution and by minimizing the heat losses using thermal screens.
- to develop a mathematical model of the greenhouse in order to check and to optimize its thermal behaviour.

This paper presents a method, for measuring the heat losses of a greenhouse which includes the influences of the wind and the sky temperature. It also provides the savings due to two different types of screens. Other energetic or agronomic results are presented in the second report of the experiment (Bourgeois 1984).

2. Material and method

2.1. Experimental set-up

The test greenhouse has a total area of 663 m² and is divided into 5 thermal zones, each zone being equipped with different low temperature heating systems. All systems combine a water-air convector

with either pipes layed on the ground, underground heat exchangers, or heated floors. The central zone (3) is used as reference, and the conventional air heating (water at 70/90 °C) is simulated by two electrical hot-air circulators.

For the 3 central zones, which are thermally equivalent, the crops are grown in soil. For the two side zones, the planting is done in rock wool (Grodan).

The whole experiment is controlled by an automatic data acquisition system which records for each zone : temperatures, relative humidity, energy flows and local meteorological parameters.

2.2. Cover and screen

The roof is single glazed; the sides are double glazed. In addition two horizontal thermal screens have been installed in each thermal zone : the upper one is just an ethylen-vinyl-acetate (EVA) sheet of 200 µm thickness. The lower one is composed of two plastic sheets separated by a 3 mm air gap, with one of the internal faces coated with chrome (Hecotherm).

Physical properties of the screens have been measured using a black body at 350 K (table 1). During the night both screens are usually unfolded. The heat requirement of the greenhouse with only one screen and without a screen have been measured during limited periods (one week). The relative effect of the screens is deduced after an adequate normalization of nightly measurements to the mean meteorological conditions.

2.3. Period of interest

The second agronomic experiment took place between September 20th and December 31st 1983. During this period 18.000 Chrysanthemums were brought to maturation. The third crop started in February to be finished in June 1984. For this experiment, 1.200 tomatoes plants were grown in the greenhouse. Most of the thermal findings presented below, result from these periods.

3. Results

3.1. Heat demands

3.1.1. Energy heat balance

During the night, the energy heat balance (heat losses = heat gains) of the greenhouse may be written as following :

$$P_s \cdot \Delta\theta \cdot \Delta t \cdot A = P_{in} \cdot \Delta t \cdot A \quad \text{MJ}$$

where P_s = specific heat losses of the zone $\text{W/m}^2\text{K}$
 $\Delta\theta$ = average indoor and outdoor temperature difference K
 Δt = duration Ms of the considered period
 A = cultivatable soil surface m^2
 P_{in} , the effective consumed power may be divided into :

$$P_{in} = P_{aux} + \Delta P_{stock} \quad \text{W/m}^2_A$$

with : $P_{aux} = \frac{E_{aux}}{A \cdot \Delta t}$ = average power delivered by the auxiliary heating systems

$\Delta P_{stock} = \frac{E_{stock}}{A \cdot \Delta t}$ = measured variation of the energy stored in the ground

Dividing by the soil surface area (A) and the time duration (Δt), one gets :

$$(1) \quad P_s \cdot \Delta\theta = P_{in}$$

This means that if one plots P_{in} as a function of $\Delta\theta$, one expects to get a straight line with a slope proportional to the specific heat losses of the considered thermal zone. Figure 1 shows the experimental results : each point is an averaged value over one night. As expected, P_{in} depends linearly on $\Delta\theta$. The observed dispersion is due to perturbations (wind effect, sky temperature ...) that will be discussed later. Once the perturbations suppressed, relation 1 may be used in order to evaluate the relative effect of the thermal screens, or of the heating systems themselves, on the energy requirements.

3.1.2. Influence of the sky temperature

Radiative heat losses between the roof and the outdoor environment is directly linked to the sky temperature. With a clear sky, the sky temperature may be 20 to 25 °C below the air temperature, with a cloudy sky the sky temperature approaches the air temperature.

The heat balance equation of the greenhouse can be rewritten considering separately the radiative exchanges to the sky (P_{sky}), the exchanges between the envelop of the greenhouse and the exterior air (P_{out}), and the exchanges due to air renewal (P_{ar}).

$$(P_{ar} + P_{out}) \cdot (\theta_{in} - \theta_{out}) + P_{sky} \cdot (\theta_{in} - \theta_{sky}) = P_{in}$$

$$\text{or } (P_{ar} + P_{out}) \cdot (\theta_{in} - \theta_{out}) + P_{sky} \cdot (\theta_{in} - \theta_{out}) + P_{sky} \cdot (\theta_{out} - \theta_{sky}) = P_{in}$$

Finally, dividing the two terms by $\Delta\theta = \theta_{in} - \theta_{out}$ we obtain :

$$(2) \quad P_{ar} + P_{out} + P_{sky} + P_{sky} \cdot \frac{(\theta_{out} - \theta_{sky})}{(\theta_{in} - \theta_{out})} = \frac{P_{in}}{\Delta\theta}$$

Thus, the influence of the sky temperature depends directly on the ratio

$$R_c = \frac{\theta_{out} - \theta_{sky}}{\theta_{in} - \theta_{out}}$$

P_{out} and P_{sky} can be connected to the conventional heat transfer coefficients : If G_{in} , G_{out} , G_{sky} are the transfer coefficient from

the glass to the plants, the outdoor air and the sky, respectively we have :

$$(3) \quad P_{sky} = \frac{G_{in} \cdot G_{sky}}{G_{in} + G_{sky} + G_{out}}$$

$$P_{out} = \frac{G_{in} \cdot G_{out}}{G_{in} + G_{sky} + G_{out}}$$

These two parameters can be estimated experimentally by plotting the effective specific loss " P_{in} " against the sky ratio R_C . In order to separate, in a first $\Delta\theta$ step, sky and wind influence, we retained only the night periods where the windspeed was lower than $1 \frac{m}{s}$. (Figure 2).

One can note that the measured value for P_{sky} ($1.5 \frac{m}{s}$) agrees with the calculated one using relation 3 : $P_{sky} = 1.4 \frac{m}{s}$. It confirms that the thermal losses depend linearly on R_C ; heat exchange with the sky represents in average about one third of the total exchange. Then for the same outdoor air temperature, the heat demands of a greenhouse may vary by more than 50 % with the sky temperature. Without screens the influence is even greater.

3.1.3. Interaction between wind and sky influence

Two parameters depend strongly on the windspeed : the air renewal rate (P_{ar}) and the convective exchange coefficient between the glass and the outdoor air (G_{out}). It results from relation 3 that both P_{out} and P_{sky} vary with the windspeed (v_{wind}).

Introducing a linear relation for the convective exchange (Mac Adams, Kreith et al : $G_{out} = G_{out 0} + G_{out v} \cdot v_{wind}$) we are able to calculate for different windspeeds the total convective and radiative heat transfers as a function of R_C , exclusive of air renewal (figure 3).

Figure 3 shows that wind and sky influences are interdependent : an increasing windspeed either augments or reduces the total heat transfer by the roof, depending on the value of R_C ; in fact at low sky temperatures, the glass temperature may be lower than the outdoor air temperature. In this case, a strong wind would raise the glass temperature and reduce the heat losses. One can note that this situation occurs oftener with screens ($R_C > 0.8$) than without ($R_C > 1.85$).

3.2. Effect of the screens

3.2.1. Influence on the heat consumption

Once P_{sky} (v_{wind}) and P_{out} (v_{wind}) known, we are able to correct the perturbation introduced by the wind and the sky temperature. We normalize measurements to the following mean meteorological conditions : $R_C = 1$, $v_{wind} = 1.2 \frac{m}{s}$.

Table 2 shows the influence of the screens on the heat consumption of the greenhouse. One can note that :

- Calculated losses agree with the measured ones. For the Hecotherm screen, the additional thermal resistance due to the internal air gap and chrome film (table 1) provides 10 % more savings than for the simple polyethylene sheet EVA. On the other hand, using two screens increases only slightly the savings (~ 5 %).
- Savings measured at CERN agree with other experiments, in particular with the results found by Bailey (Bailey B.J. 1977).

3.2.2. Influence of the screens on the vertical temperature gradient and leaf temperature

Figure 4 shows that the use of thermal screens strongly reduces the air temperature above the screens : this temperature stabilizes itself between the outdoor air and the indoor air temperature : it does agree with the 50 % energy savings.

On the other hand, below the screen the influence of the heating systems is predominant and the screens do not modify the temperatures much. However with screens, the leaf temperature of the plants at 0.5 m. was in average between 0.2 °C (heating pipes layed on the ground) and 0.5 °C (hot air convector) higher than for unscreened plants at the same air temperature.

4. Discussion and conclusion

This investigation has shown that the sky temperature influence on the heat consumption cannot be neglected.

As wind and sky influences are interdependent, thus they have to be studied together.

In the Swiss conditions, a thermal screen is able to reduce by about 50 % the nightly heat requirement.

References

- Bailey B.J. 1977. Thermal screens for reducing heat losses from greenhouses. Acta Hort. 70 : 26 - 32.
- Bourgeois M. et al. 1984. Serre pilote CERN, Rapport No 2 CERN/DIR/EN 84-2, Genève
- Kreith F. et al. 1978. Principles of Solar Engineering Hemisphere, Washington, p. 139.

Table 1 - Optical properties of the screens for blackbody radiation at 350 K

	Transmission	Absorption	Reflection	Internal thermal resistance
EVA	3.8 %	79 %	17.2 %	-
Hecotherm	0	75 %	25.0 %	0.08 m ² K/W

Table 2 - Measured and calculated heat losses of the greenhouse, without and with screens. Perturbations due to wind and sky temperature have been already suppressed

	Calculated specific loss W/m ² K	Economy due to screen %	Measured specific loss W/m ² K	Economy due to screen %	Economy in % of loss through roof %
Without screen	10.2	-	10.0	-	-
Hecoth.+EVA	5.7	44	5.8	42	52
Hecotherm	6.5	36	6.2	38	47
EVA	7.2	29	7.1	29	36

Figure 1 - Effective consumed power of the greenhouse as function of $\Delta\Theta$ for the night period. Average night value.

Figure 2 - Effective specific loss as function of the sky ratio $R_c \cdot V_{wind} < 1 \frac{m}{s}$. Average value over one night. s

Figure 3 :
Calculated total
convective and radiative
heat transfer as a
function of R_c , for
different windspeeds :

$$P_s^* = P_{out}(v) + P_{sky}(v) \cdot (1 + R_c)$$

Temperatures :

- Air : sensor without ventilation
- Air : ventilated sensor
- Glass
- Upper screen EVA
- Hecotherme screen : inferior side
- + Leaves
- Soil

With two screens : 5 january 1984 windspeed : 1.0 m/s sky temperature : -5.5 °C
Percentage of heating assumed by the pipes on the ground : 94 %

Without screen : 7 january 1984 windspeed : 0.4 m/s sky temperature : -12.2 °C
Percentage of heating assumed by the pipes on the ground : 60 %

Figure 4 : Vertical air temperature gradient during the
night. Mean value from 0 to 6 a.m.