

TRANSPIRATION AND TEMPERATURE OF GREENHOUSE CROPS, IN RELATION TO INTERNAL AND EXTERNAL RESISTANCES

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Abstract

Temperature and transpiration of a canopy are the outcome of the balance of all energy fluxes to and from the canopy. The partition of available radiative energy is determined, at least partially, by some resistance to transfer of a related flux. Transfer of sensible heat is restricted by the resistance of the boundary layer (external resistance). On the other hand, since vapour is produced somewhere beneath the external surface of a leaf, an additional (internal) resistance has to be accounted for, when transfer of latent heat is considered.

Most climate control actions do affect many more variables than the one(s) they are meant to influence, and are thus likely to result in the alteration of one or both resistances; such variation may enhance or limit the outcome of the control action. Accordingly, both the (undesired) effects on the canopy of any control operation and the effectiveness of any such procedure, when aimed at control of canopy temperature or transpiration, have to be carefully assessed.

Some first results are shown, of an experiment allowing for a concurrent appraisal of the internal and external resistances of a greenhouse tomato crop. The magnitude and variations of both resistances are shown for a typical 24 hours period. Although no conclusions can be drawn yet, it may be pointed out that the day/night cycle of the internal resistance is of overwhelming importance. Smaller variations of the external resistance can be observed, as resulting from a change in temperature of the heating system and a sudden opening of the windows.

1. Introduction

Today's advanced horticulture allows for greenhouse microclimate to be totally controlled. However, most climate control actions do affect many more variables than the one(s) they are meant to influence. The outcome of any such procedure may, accordingly, be enhanced or limited by those (undesired) effects.

The most obvious means to affect temperature or transpiration of a canopy are to tamper with either irradiation (heating, screening, lighting or shading; figures 1 and 2) or the saturation deficit of the air (ventilating, heating or cooling; figures 2 and 3). It is appreciated, in fact, that temperature and transpiration are the outcome of the balance of all the energy fluxes to and from the canopy. The partition of available radiative energy, however, is determined, at least partially, by some resistance to transfer of a given flux. Any of the mentioned practices results always in an alteration of those resistances, whose extent and consequence have, therefore, to be carefully assessed.

A detailed discussion of the theoretical problems involved in the

use of the resistance formalism, of the assumptions needed and their validity, is out of the scope of the present paper. It will suffice to state here that a resistance to heat transfer (external resistance) - from the leaf surface to air at some reference height in the greenhouse - is defined by the transport equation of heat:

$$r_e = \rho c_p \frac{T_o - T_a}{H} \quad \text{s.m}^{-1} \quad (1)$$

where:

- ρ = the density of air (kg.m^{-3})
- c_p = its specific heat at constant pressure ($\text{J.kg}^{-1}.\text{K}^{-1}$)
- T_o and T_a are the temperature of the leaf surface and of air at reference height, respectively (K)
- H = the flux density of sensible heat (W.m^{-2}).

A resistance to vapour transfer r_v , can be defined in a similar way as:

$$r_v = \frac{\rho c_p}{\gamma L} \frac{e_o - e_a}{E} \quad \text{s.m}^{-1} \quad (2)$$

where:

- γ = the thermodynamic psychrometric constant (Pa.K^{-1})
- L = the latent heat of vaporization of water (J.kg^{-1})
- e_o and e_a are the vapour pressure at the evaporation surface and of air at reference height, respectively (Pa)
- E = the flux density of vapour ($\text{kg.m}^{-2}.\text{s}^{-1}$).

When the similarity of transfer in air of vapour and heat is assumed, and the fact that the phase transition takes place somewhere beneath the external surface of a leaf is appreciated, it is easy to see that the resistance to vapour transfer must be equal to the external resistance added to some "internal" resistance r_i , defined by:

$$r_v = r_e + r_i \quad \text{s.m}^{-1} \quad (3)$$

In the literature the external and internal resistances are commonly identified with the boundary layer and stomatal resistances, respectively. This practice has been avoided here, since boundary layer for a greenhouse canopy is a definition with a rather elusive meaning. On the other hand, use of the word "stomatal" resistance would imply that vapour can reach the external surface of a leaf only through the stomata. Such restriction is actually not needed in the present context.

It is easy to infer - and there is plenty of literature evidence about - that the two resistances are largely independent of each other, i.e. they are affected in a different way by the microclimate, and a separate parametrization of them makes indeed practical sense. To be sure, there is also a physiological influence on both: dimension of stomata, their density, thickness of the cuticle etc., concur in determining the internal resistance (Lee, 1967; Körner, 1979) while leaf size, shape, orientation etc., can be expected to play a role in the external one (Parkhurst et al., 1968; Lim, 1969; Vogel, 1970).

2. Material and methods

It will be clear that, to allow for an appraisal of internal and external resistances as function of greenhouse climate, all the quantities

appearing on the right hand side of equations (1) and (2) have to be measured for a greenhouse crop, together with the relevant parameters of the microclimate. Such a research was carried out in one of the glasshouses of the Institute of Agricultural Engineering, Wageningen, The Netherlands. There, tomatoes were grown on rockwool mats, heating being provided by low laying, hot water pipes. Transpiration was determined by in turn weighing a portion of a crop row (4 plants) grown on a tray, held at ground level (figure 4). The electronic scale used at this purpose allowed - after some artifices - for an accuracy of $5 \cdot 10^{-6}$ i.e. roughly 1% and 10% of 5-minutes day- and nighttime transpiration, respectively, of a mature crop. Leaf area of the weighed plants was estimated from mean leaf length using the method developed by Van der Varst and Postel, 1972. Dry and wet bulb temperatures of greenhouse air at two meters height were measured with an Assmann aspirated psychrometer, with thin thermocouples (0.1 mm) glued to each bulb. Temperature of the leaf surface was provided by 6 thermocouples sets (of 5 each) held touching the lower surface of leaves at 3 heights in the canopy and with various orientation (figure 5). The mean of all the thermocouple values has been used as leaf temperature for the present calculations and the evaporating surface was assumed to be saturated at that temperature.

Flux of sensible heat to and from a leaf is normally a much smaller energy flux than either transpiration and radiation, so that appraisal of it from the energy balance of the surface would yield unaffordable errors. For this purpose it was made use of synthetic, not transpiring leaves. The contribution of net radiation flux to their temperature was accounted for by the use of pairs of identical leaves, only one of them being kept, by a known electrical current, a few degrees warmer than the air (figure 6). In this way the power being supplied and the difference in temperature between the two leaves are related to the external resistance through an equation formally identical to (1). The inaccuracy of the assumptions about net radiation was minimized by an aluminium coating, while the difference in longwave emittance was accounted for. Although 11 pairs of leaves of different shapes and forms were scattered throughout the canopy, the results mentioned hereafter refer to a leaf having the mean length (5.5 cm) of the size distribution of the leaves of the canopy during the experiment, and a similar shape.

3. Results and discussion

An accurate processing of the data has still to be performed, therefore only a limited discussion will be provided here.

Equations (1) and (2) were used to deduce r_e and r_v from the measures, r_i being then given by (3). Their course for a typical spring day is shown in figure 7, superimposed to the path of shortwave radiation incoming above the glasshouse. It can safely be stated that of overwhelming importance is the day/night cycle of internal resistance, and that a remarkable inverse correlation between the latter and shortwave irradiation is to be observed at daytime also.

No conclusions can be drawn yet about the fluctuations of nighttime internal resistance: it has to be kept in mind, however, that the relative error in its estimate becomes larger as transpiration becomes smaller, as pointed out in § 2. The external resistance, on the other hand, exhibits only a minor day/night trend, arguably due to a similar trend in air movement. Shorter term variations can be mostly traced to cycles in pipe heating or in ventilation.

Previous wind tunnel experiments with similar methods had mostly been performed in unrelated circumstances, being either wind speed (Thom, 1968; Wigley and Clark, 1974) or leaf temperature too large (Vogel, 1970) for the present issue. Extrapolation of their results yields values somehow larger for the external resistance of leaves of the same size. Accounting for the irregular shape (Vogel, 1970) or for the turbulence introduced in the airflow by neighbouring leaves (Sunderland, 1968) does reduce the expected outcome for the resistance.

From the results shown here it could be argued that the control of transpiration water losses is mainly internal, thereby bringing some contribution to a dispute that has been going on in the literature precisely on this matter (Idso, 1983, reviewed the question). It is the present author's opinion, however, that the extent of naturally occurring internal resistances and the marked significance of leaf size (as confirmed also by the present experiment) in defining the external one, rule out the chance of any clear cut conclusion.

Acknowledgements

Financial support for the research from the Dutch Ministry of Agriculture is gratefully acknowledged. The help of Dr.Ir. G.P.A. Bot in devising the set-up has been invaluable and Dipl.Phys. J.A. Stoffers contributed many useful ideas to it. A. Jansen and P. Jansen produced the thermocouples sets and the artificial leaves with their remarkable skill. The good will of F.J.M. Corver, C.J. Lamers and L.B.M. Romijn has been priceless in keeping the crop healthy in spite of the experiment.

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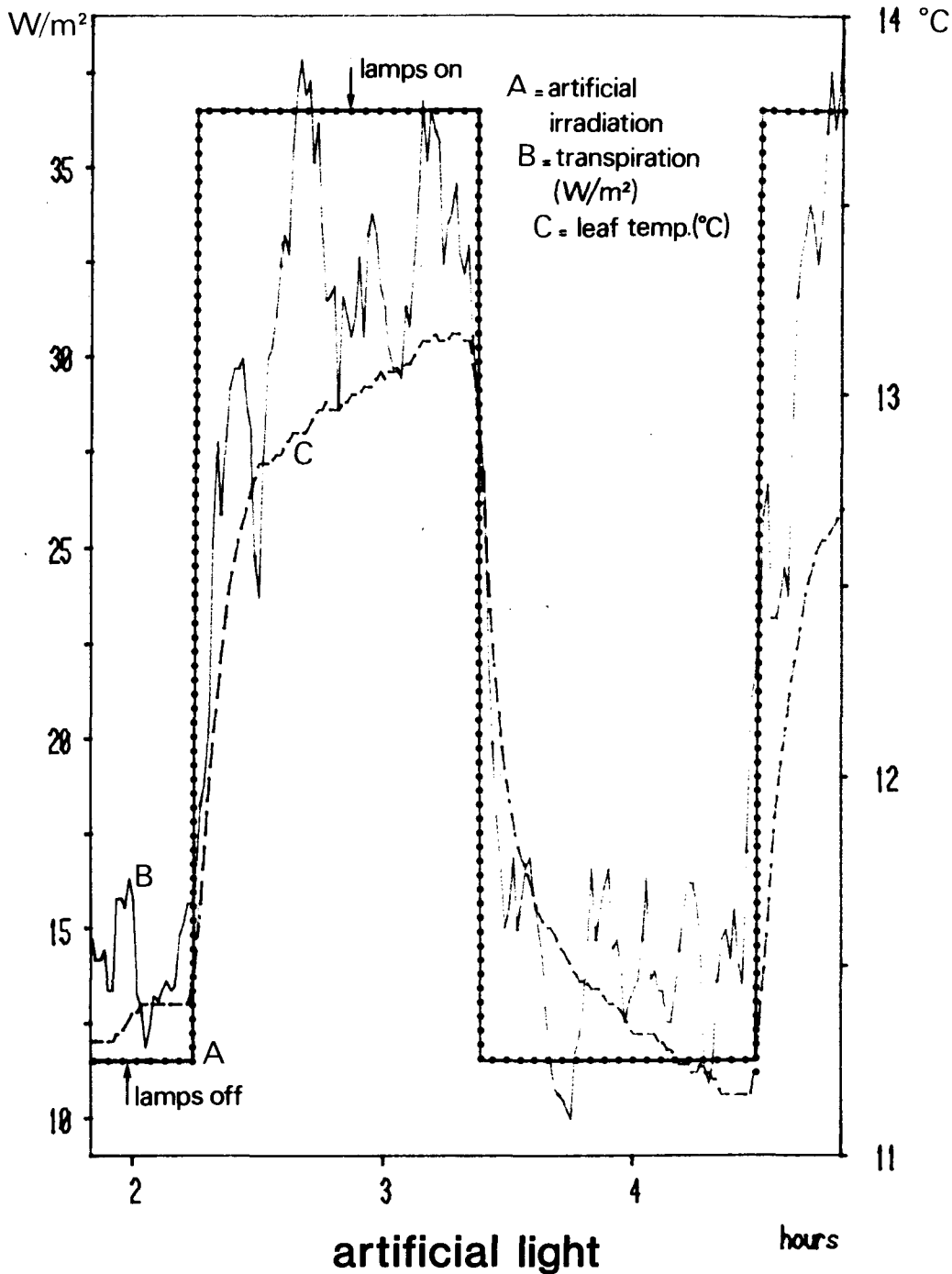


Fig. 1 Measured transpiration and leaf temperature while supplying and withdrawing artificial irradiation. Measures were performed during a spring night, no heating nor ventilation being then provided.

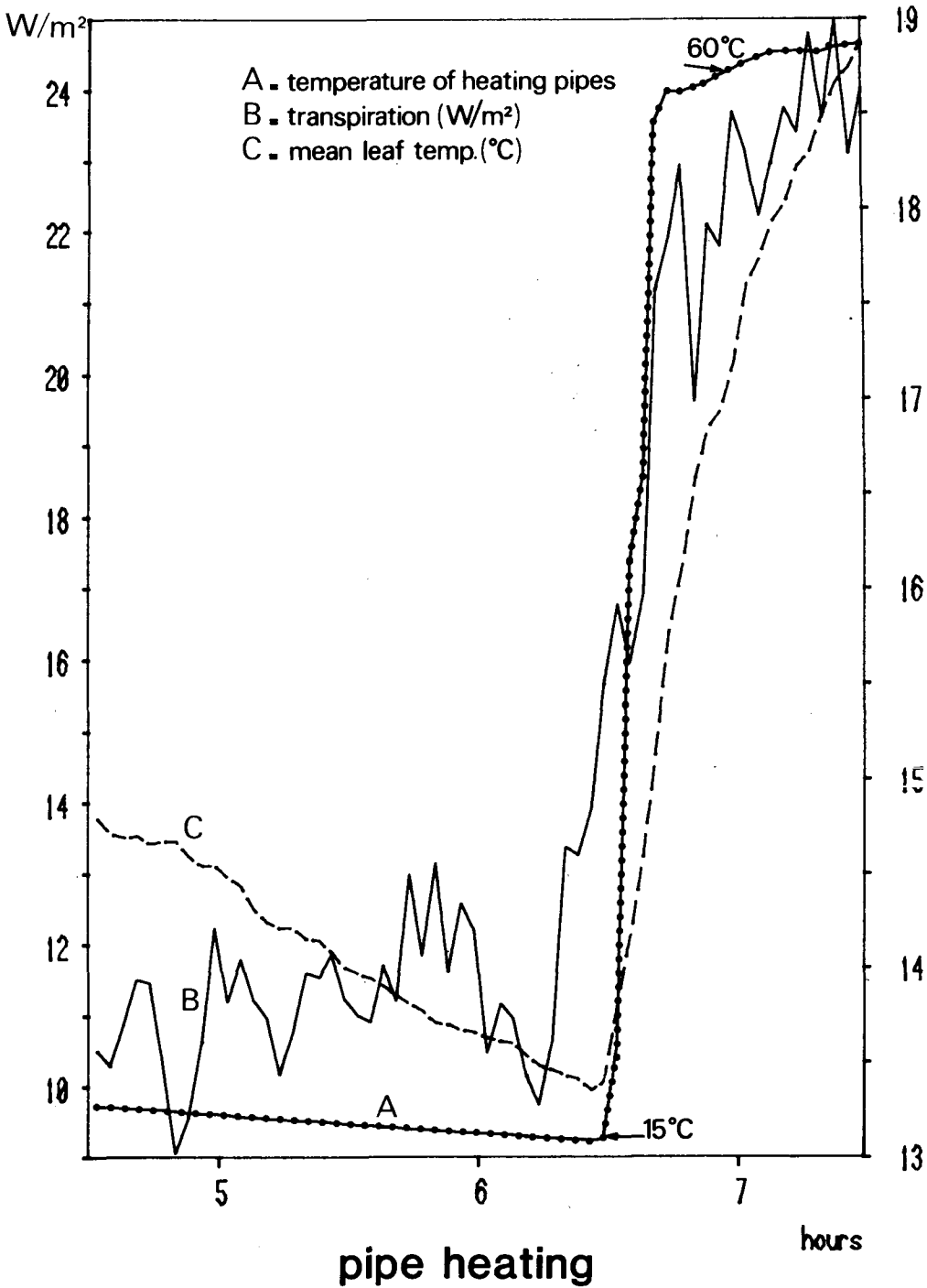


Fig. 2 The same as fig. 1 while rising temperature of the heating system. Sunrise was at 7.30.

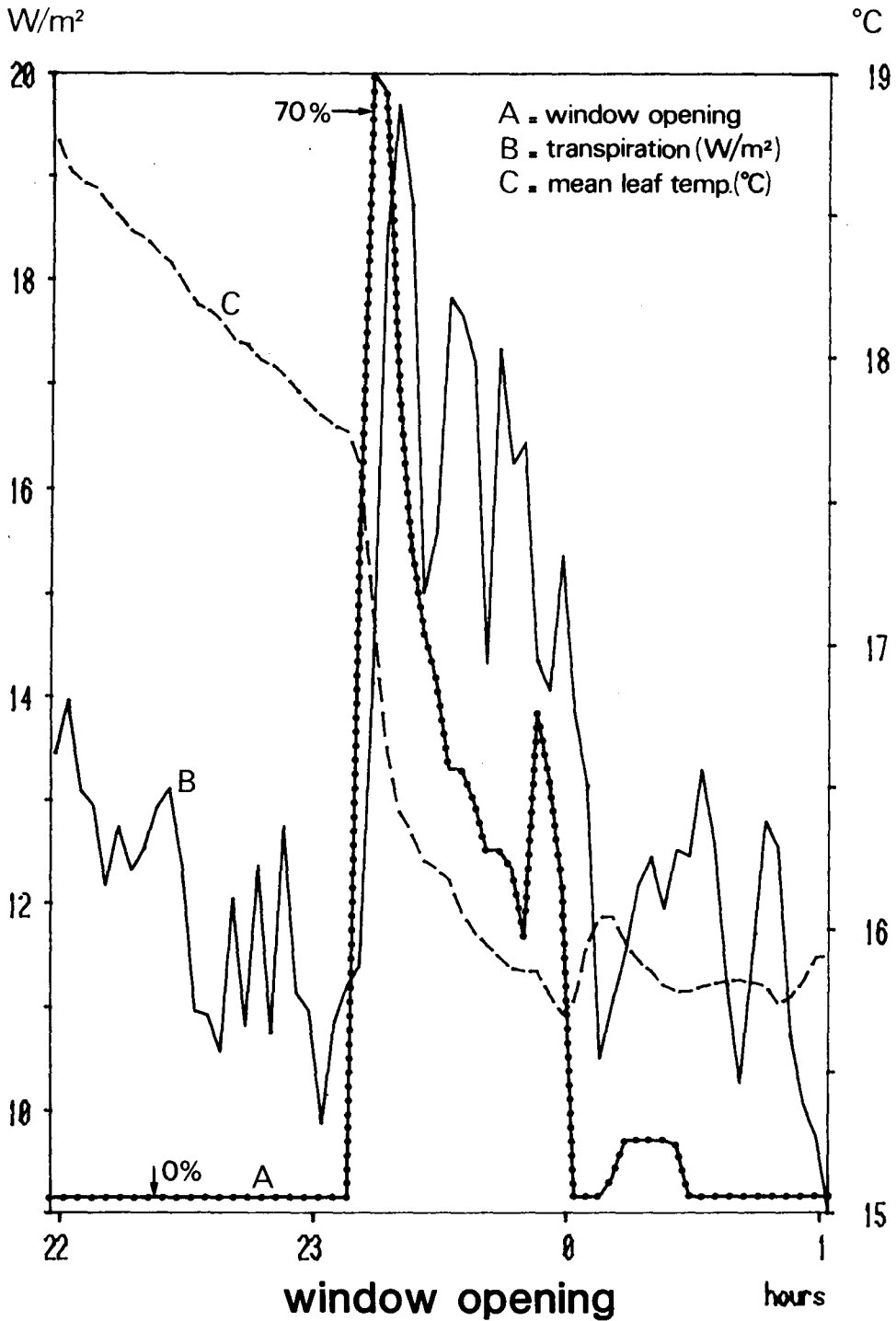


Fig. 3 As fig. 1 while ventilating. No heating provided.



Fig.4 - The scale as installed i
the glasshouse. The alu-
minium tray bearing the
plants can also be seen.

Fig.5 - One of the thermo-
couple sets used
to measure temper-
ature of the
leaves.



Fig.6 - A pair of alumi-
nium coated arti-
ficial leaves.
See text



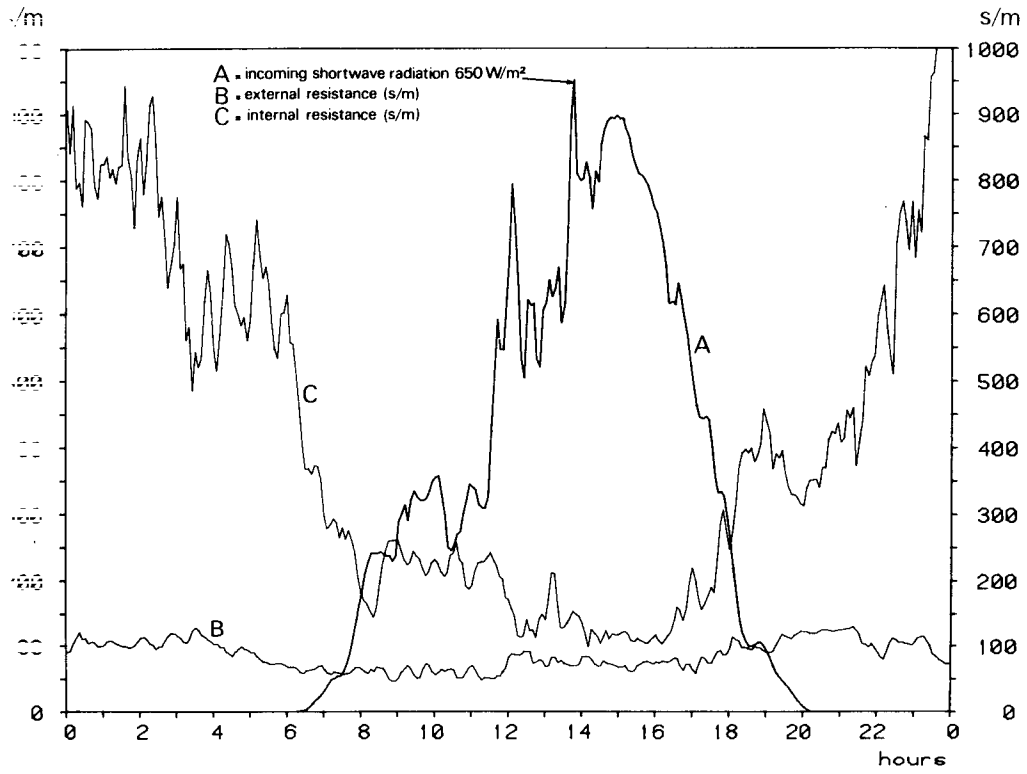


Fig. 7 Daily course of internal and external resistances for a spring day. The bold line shows the corresponding shortwave radiation incoming above the house.