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The radiation monitor is an internet application that shows the effect of covering materials, screens, heating and illumination on the temperature distribution in the crop region of a greenhouse crop.
It is meant to help with the strategical and operational discussions in greenhouse climate control.

This document gives an explanation on the user interface and presents the

Theoretical background.

The software was developed by Wageningen UR Greenhouse horticulture

Sponsors

The software was developed with the support of a large group of supply companies and supported by the research program Kas Als Energiebron of the Ministry of Economic affairs and representatives of the Dutch horticultural sector.
Click on the names of the supporting companies for further presentations.

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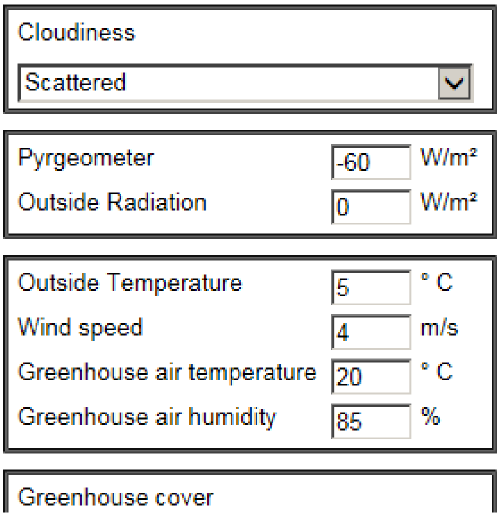
User Interface

The left pane of the interface gives the inputs used for the computations whereas the right pane shows the [results of a computation].

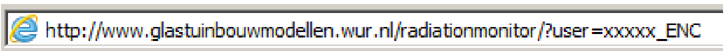
Input pane



Radiative energy loss of a greenhouse is strongly influenced by the cloudiness of the sky.
Some greenhouses are equipped with a pyrgeometer, a device that tells this radiative heat loss so growers used to such a device might fill in the Pyrgeometer reading to characterize the sky conditions. People that do not know the typical values of the radiation loss to the sky will prefer to use the descriptive parametrisation of the sky conditions (‘Clear’, ‘Scattered’ or ‘Overcast’). Note that when changing the description the Pyrgeometer value will change to corresponding typical figures.

This is the solar radiation

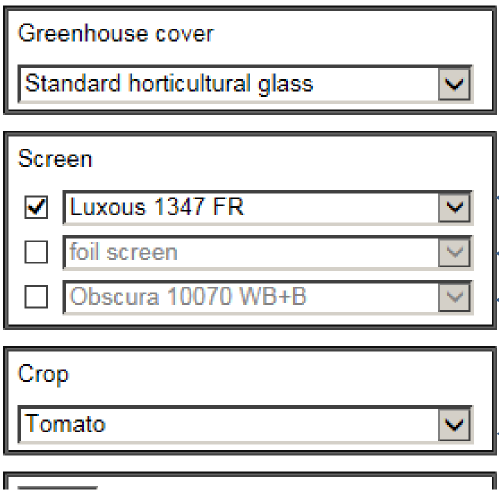
The temperature can be expressed in Centigrade or in Fahrenheit. To change to Fahrenheit you have to change the last C in the address in your browser to an F (or vice versa)



Here you can define to which temperature the greenhouse is heated. In cold conditions the model will compute the heating needed to reach this temperature. In warm conditions or conditions with a lot of solar radiation, the model will determine a ventilation rate that establishes this temperature (if possible)

Here you can define the humidity in the greenhouse. The model does not take the humidity balance into account (but does account for transpiration, see explanation of the crop selection box). The value filled in here is used to compute the dew point temperature of the greenhouse air and in the crop transpiration computation.

Input pane (continued)

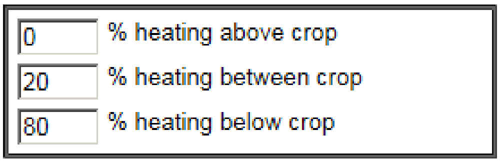


Here you can select an appropriate greenhouse cover. The list contains a number of typical greenhouse coverings, ranging from glass to poly coverings and can be single or double.
For each of the coverings the model uses typical properties for its transmissivity for solar radiation, convective exchange and its transmissivity for thermal radiation.

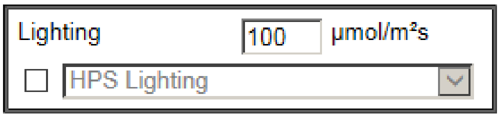
Here one can select to use none up till three screens. For each screen used, the type of screen can be selected from a list. The properties of each screen in the list were determined in the Wageningen UR Greenhouse horticulture Lightlab.
The properties of the screens are described [here].

The radiation monitor has a number of crops for which the optical properties and typical architecture was determined by the Wageningen UR researchers.
For all crops the full grown crop is considered. Also, for each crop the typical transpiration is taken into account, being a constant base transpiration and a light dependent component.
The crop parameters that are used are listed [here].

Input pane (continued)



Heating systems in greenhouses can be located below the crop, in between the crop or as an overhead heating system.
Here you can determine what percentage of the heating power is released where in the greenhouse. Of course the sum of the percentages should be 100.
Normally only one or two systems will be used.
When changing from one crop to another, the default heat distribution over the different systems may be changed.



When using artificial illumination the type of illumination can be selected (HPS or LED) and the intensity can be defined (in µmol/(m² s) PAR radiation.
The parameters used for the different light-sources are described here

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Output pane

The virtual sky temperature (computed from the combination of pyrgeometer value and outside temperature)

Outside temperature
(a copy of the filled in value)

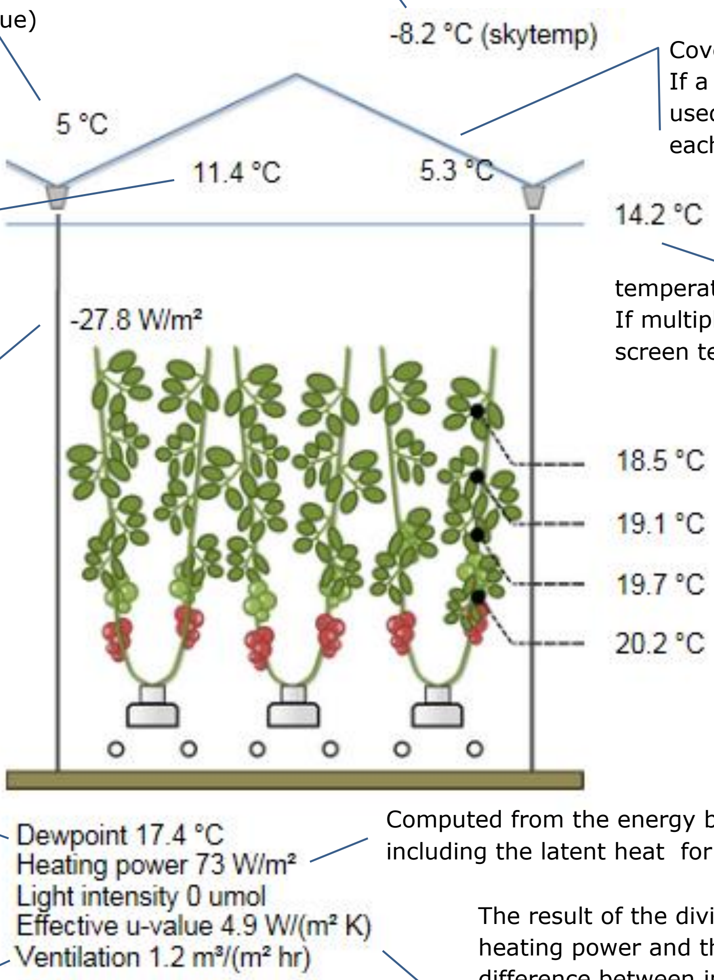
Cover temperature.
If a double layer cover is used, the temperature of each pane is shown.

Temperature above the screen(s) (only shown when at least one screen is used)

Computed screen temperature(s).
If multiple screens are used each screen temperature is shown.

Net radiation on the top-of-crop level.
This is the sum of shortwave radiation gain and long wave radiation loss

Crop temperatures at four locations



Computed from the combination of temperature and RH

Computed from the energy balance of the greenhouse, including the latent heat for the crop transpiration

The light intensity at the top-of-crop level

The result of the division between the heating power and the actual temperature difference between inside and outside.
This computation includes the lowering effect of light sources (lamps and/or sun) and the increasing effect of crop evaporation on the apparent u-value.

The computed ventilation.
In cold conditions it will be the leakage ventilation

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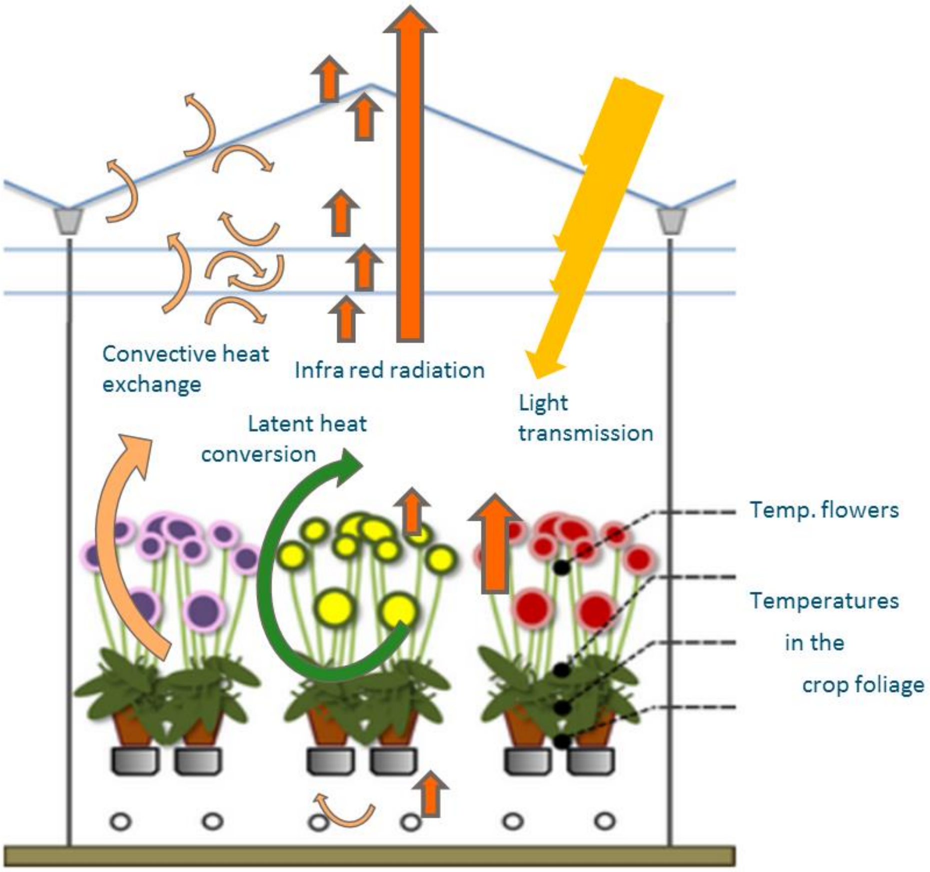
Theoretical Background

The climate conditions in a greenhouse are the result of the interaction of the outside climate with the enclosure and the canopy inside the enclosure. During daytime, solar energy is trapped in the greenhouse. Shortwave solar radiation passes the transparent cover, but the heat, generated by absorption in the crop and construction elements, is prohibited to escape from the enclosure.

During night time, in modern greenhouses it is the heating system that assures a favourable inside air temperature, although the energy stored in the soil might as well provide some energy supply. For unheated greenhouses, this night time energy supply from the soil, or sometimes also additional elements with a large thermal mass, is the only and therefore the primary energy source. However, this dynamic behaviour of greenhouses is not taken into account in the Radiation monitor. It uses a **steady state approach**, which means that the temperatures computed are the temperatures that would be achieved when the environmental conditions would remain constant for an infinite long time.
Of course this will not be the case in reality, but since the thermal mass of all components in a greenhouse, except for the soil is small, the steady state approach is a sound way to compute the effect of screens and covering material on the **temperature profile in the crop**, which is the objective of this tool.

The model was designed to do simulations for **low-light** conditions (from darkness up to 150 W/m² outdoor light) and for **cold conditions**. This means that the model assumes that crop transpiration is not limited by drought or temperature stress and that, the ventilation capacity of the vents is always enough to achieve the temperature that the user provides as an input.

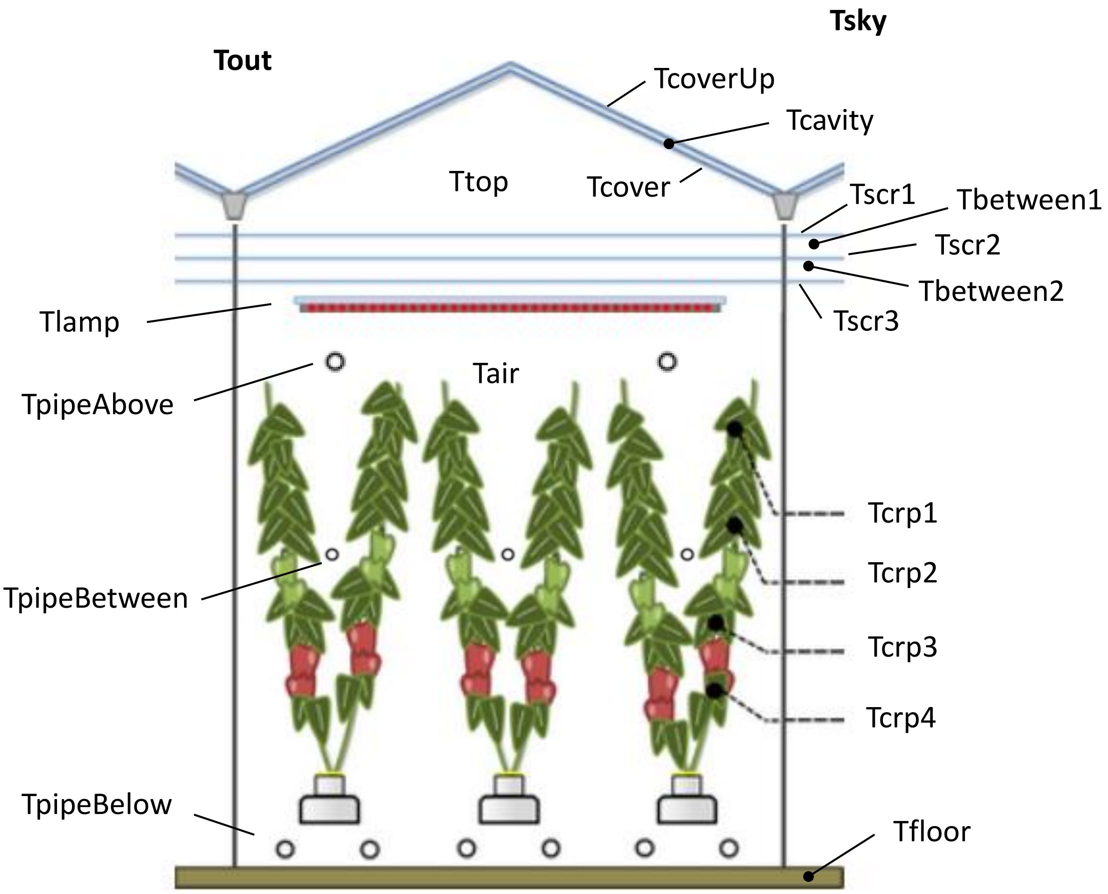
In a steady state solution, where all temperatures are at an equilibrium value, the sum of the energy fluxes from and to all the greenhouse elements is zero. When looking at the picture below, this means that for instance the cover temperature is at such a value that the energy gained by the absorption of light in the glass (typically 4% of the solar radiation) plus the



radiative and convective heat received from the warm greenhouse below the glass equals the radiative energy loss to the sky and the convective energy loss to the air.

Of course, things like the absorption of shortwave radiation and the emission of thermal radiation to the sky are dependent on the physical properties of the covering material. These properties are defined in laboratory measurements and entered in the model by parameter lists specific for the materials selected (*e.g.* the type of cover, the type of screen, lamps and crop).

In the model the energy exchange is computed between the distinguished state variables. State variables are the nodes in a heat exchange network that represent the 'containers' that absorb or supply energy, dependet on the temperature difference between two of such states. The picture below shows all the state variables in the model.



The state variables Tout and Tsky are marked in bold because they are the boundary variables which are opposed to the model. All other temperatures are computed by the model by an iterative procedure that finds the equilibrium temperature in such a way that the computed air temperature matches the temperature entered by the user.
In order to do so, the energy supply to the heating pipes is increased in case the equilibrium greenhouse air temperature shows out to be below the user defined value. The increment is performed by iteration until the right air temperature is obtained.

External flux
During this iteration, the heating power is opposed to the model as an **external flux**. This means that the energy flux has a value independent of the temperature of the state variable to which it is directed.

Besides the heating power, the sun acts as an external flux onto the model and also the electric energy from artificial illumination. With sunshine or artificial illumination, the greenhouse may become too warm, even with heat supply to the heating pipes 0. In that case, the model will increase the ventilation rate through the vents, while keeping the heat supply to the pipes 0. This can be seen in the output-screen, where the ventilation rate is shown to be increased.

Where the external fluxes representing the heating and the absorption of light add energy onto the balance, the crop transpiration extracts energy from the balance.

Crop transpiration
When leaves of a crop evaporate water, energy is converted from sensible heat to latent heat. At higher intensities of solar radiation or artificial illumination, this energy originates almost all from the absorption of the shortwave radiation, but at night, this energy is derived from the environment. This requires that the leaf temperature is below the ambient temperature. At a certain point, an equilibrium temperature will be found where the energy needed for transpiration equals the energy supply from the warm environment to the colder leaf.
The transpiration rate is driven by the difference between the vapour content of the air volumes inside the leaves and the vapour content of the surrounding greenhouse air. The vapour content in the leaf equals the saturated vapour content at the leaf temperature and the greenhouse air vapour content follows from the user defined temperature and relative humidity.

As a formula, the transpiration can be described as:

$$\text{transpiration} = A_{leaf} \times 2 \times (X_{leaf} - X_{air}) / \text{resistance} \qquad [\text{gram/s per leaf layer}]$$

'A_{leaf}' denotes the total surface of leaves associated to a leaf layer in the model. The surface is multiplied by 2 because a leaf has two sides. The fact that the upper side of leaves has less stomata than the bottom side is incorporated by the value fitted as the stomatal resistance.

X_{leaf} is the moisture content of the air volumes inside the leaf and X_{air} is the moisture content of the greenhouse air, both in gram/m³.

The saturated moisture content of air at a certain temperature can easily be computed by the formula below.

$$X^* = 1255 * 10\text{^}(7.9 * \text{Temp}/(237 + \text{Temp})) / (273 + \text{Temp}) \qquad [\text{gram/m}^3]$$

The moisture content of the air inside the leaf follows by filling in the leaf temperature in the formula. When using this formula after replacing 'Temp' with the greenhouse air temperature and multiplication by the relative humidity, the absolute moisture content of the greenhouse air is obtained.

The resistance for moisture transport from leaf to air is the sum of the boundary layer resistance and the stomatal resistance.

$$\text{Resistance} = \text{boundary layer resistance} + \text{stomatal resistance} \qquad [\text{s m}^{-1}]$$

The boundary layer resistance is dependent on the temperature difference between leaf and surrounding air and by the local wind speed, but the influence of these factors shows to be very small, especially in the conditions for which the radiation monitor is supposed to be used (dark and cold periods). Therefore, the radiation monitor uses a fixed value for the boundary layer resistance: 300 sm^{-1}.

The stomatal resisatance is determined by the opening of the stomata and is therefore a strongly varying variable. In general, the stomatal resistance is high during the night and low during the day. Many authors present relations to determine the stomatal resistance from the environmental conditions (*e.g.* the work of Stanghellini), but in all publications known to the author, the parameterisation of the influencing factors is based by fitting the results of a lumped crop model on measured values. In a lumped crop model there is only one temperature, one vapour concentration difference and one radiation flux (the one at the top of the canopy). The radiation monitor has 4 crop layers, each having its own radiation intensity, temperature and, therefore, vapour concentration difference. This different approach requires a new parameterisation.

In the Radiation monitor project, this parameterisaton was carried out by comparing computational results with transpiration data obatained from weighing gutters in two tomato experiments. It was attempted to use an as simple as possible description of the stomatal behaviour, so only light intensity was used as influencing factor. Also, the use of a single, continuous function for day and night was taken as a prerequisite.

By applying the simple formula

$$r_{i,V} = 30 * \frac{Is + 700}{Is + 20} \qquad [s\ m^{-1}]$$

A stomatal behaviour was found that very well predicted the transpiration flux from this 4 layer model. In this formula, Is denotes the shortwave light intensity to which a layer is exposed (see next section).

The formula was fitted on the transpiration from a tomato crop, but in the Radiation monitor other crops can be selected as well. At the moment Wageningen UR has no detailed data on which a paramaterisation for the other crops can be carried out, so therefore other crops are simulated by simple multiplication factors on the stomatal resistance of tomato. The multiplication factors used and the other crop-related parameters are stated in the section crop parameters. Tomato is the crop with the highest transpiration and pepper the one with the lowest transpiration (15% less).

On top of the reduction factor for crops other than tomato, the model applies an increased stomatal resistance when going down from the top layer to deeper layers. This to account for a lower transpiration from old leaves as compared to younger leaves. The second layer has a 10% higher stomatal resistance, the third a 20% higher and the bottom laywer a 30% increment of the stomatal resistance.

With a radiation intensity different for each layer (see next section) the stomatal resistance can be computed per layer. And with the vapour concentration difference the transpiration flux per layer can be computed.
This transpiration flux gives a latent heat flux according to:

LCroplayer = 2.45e3 * Transpiration [W]

in which 2.45e3 is the latent heat of evaporation of water in air in J/gram and Transpiration refers to the transpiration rate in a crop layer in gram/sec.
Of course the computation of the transpiration from a leaf layer is an iterative computation because the transpiration affects the leaf temperature and the leaf temperature affects the driving force for the transpiration.

Short wave radiation
In the present model, short wave radiation originates from two sources, the sun and the artificial illumination. For the sun, as it passes through the layers from the top cover down to the floor, each layer absorbs a fraction, reflects a fraction and transmits the remainder.

The absorbed fraction is a forced energy input for such a layer. The transmitted fraction passes energy to the layers below and the reflected radiation passes energy to the layers above.

This is a typical recursive process where at each layer the downward flux is passed attenuated further down, while generating an upward reflective flux which will be transmitted upward, but also partly scattered back. This recursive process is programmed as follows

```
function [A, Ru]=raytrace(I, layer, t,r, A,Ru)
% I = the radiation intensity (positive is downward, negative is
% upward to a certain layer)
% layer = the layer to which the radiation is directed
% t and r = the transmission and reflection coefficient of the surface.
% the current version makes no difference between the upper and the lower
% side of the surfaces, but this can, of course easily be added later.
% A = the absorbed radiation by each layer and is passed into and out of
% the function for the house keeping on the energy flux
% Ru = the eventually upward reflected radiation (leaving the
% top-most layer

if (layer==0) % this means that there is an upward radiation flux
              % coming from the top-most layer. This contributes to the
              % upward reflection out from the greenhouse system
    Ru=Ru-I;  % it is always an upward flux when directed to layer 0
    return;
end;

if (I>0) % downward radiation
    Iup = I*r(layer);
    Ido = I*t(layer);
else     % the incoming radiation is upward
    Iup = (-I)*t(layer);
    Ido = (-I)*r(layer);
end

if (Ido> 0.0001) % there is a new meaningful downward flux
    [A, Ru]=raytrace(Ido, layer+1, t,r, A,Ru);
end
if (Iup> 0.0001) % there is a new meaningful upward flux
    [A, Ru]=raytrace(-Iup, layer-1, t,r, A,Ru);
end
A(layer)=A(layer)+abs(I)-Iup-Ido;
```

To use the recursive code (the function raytrace calls itself) the transmission and reflection data of the layers have to be defined (as a vector of figures between 0 and 1) and the initial radiation has to be given. For solar radiation, the initial radiation enters the recursive function at the top, so at level 1. For radiation from the artificial illumination, the downward flux enters the recursive function at level 7 (level 1 is the outer greenhouse cladding, level 2 is the inner greenhouse cladding (if using double cladding) level 3, 4, and 5 are the screens, level 6 are the luminaires of the artificial lighting and level 7 are the pipes of the upper heating system (if any)).

The transmission and reflection vectors with some typical values are stated below

layer	transm.	refl.	comment

CoverUp	0.86	0.1	
Cover	0.86	0.1	are 1 and 0 when using single cover
Scr1	0.8	0.15	
Scr2	0.8	0.15	are 1 and 0 when screen not used
Scr3	0.8	0.15	
Lamp	0.97	0	illumination has negligible reflection
PipeAbove	0.96	0	heating pipes have negligible reflection
Crp1	0.6	0.05	
Crp2	0.5	0.05	
PipeBetween	0.96	0	heating pipes have negligible reflection
Crp3	0.4	0.05	
Crp4	0.4	0.05	
PipeBelow	0.94	0	heating pipes have negligible reflection
Floor	0	0.25	

Suppose that an actual greenhouse configuration has the radiative parameters as listed above, the solar radiation intensity at the top of each layer and the absorbed amount of light (as percentage of the outside radiation) would be the following

layer	transm.	refl.	As percentage of outside radiation	
			Light intensity	Light absorbtion
CoverUp	0.86	0.1	100	5.0
Cover	0.86	0.1	88	4.3
Scr1	0.8	0.15	78	1.8
Scr2	0.8	0.15	71	1.6
Scr3	0.8	0.15	64	1.4
Lamp	0.97	0	58	1.7
PipeAbove	0.96	0	56	2.4
Crp1	0.6	0.05	54	19.7
Crp2	0.5	0.05	33	15.1
PipeBetween	0.96	0	17	0.7
Crp3	0.4	0.05	16	8.9
Crp4	0.4	0.05	6	3.7
PipeBelow	0.94	0	3	0.18
Floor	0	0.25	2	1.7

When adding all figures, it follows that in total 68% of the radiation is absorbed and since the floor is not transmitting any shortwave radiation, 32% of the radiation is actually reflected out of the greenhouse. It can also be seen that the crop absorbs 48% of the solar radiation. This might seem to be low, but don't forget that in this example the greenhouse has a double cover, three screens and some light intercepting equipment above the crop.

The recursive scheme can be used for light entering at any level and in the model it is therefore used to compute the radiation intensity form the sun and from the lamps.
The resulting absorptions act as an external flux of energy to the specified layers.

Besides the external fluxes with their constant values, the model computes a large number of fluxes who's values are dependent on the temperatures of the state variables. Bij changing the temperatures iteratively, the equilibrium temperatures can found.
To do so, the model distinguishes two types of energy exchange processes, other than the above mentioned externally determined fluxes. First there is the energy exchange through

physical displacement of air with different temperatures, the so called convective heat exchange. The second type are the radiative heat exchange fluxes. The computation and parameterisation of all these fluxes are described below.

Convective heat exchange

Convective heat exchange brings energy from a warm place to a cold place by the movement of air. The air movement can be driven by density differences that are caused by temperature differences, but also by air movement through mechanical ventilation or wind. The first type is called **free convection** and the second is called **forced convection**. The present model distinguishes only one forced convective flux and that is the air exchange between the outside air and the inside air below the roof, which can be the top-compartment (Ttop) or the main greenhouse air compartment (Tair), depending on whether or not a screen is deployed.
So with at least one screen deployed, the energy exchange by forced convection between the outside air and the top compartment follows:

HTopOut = fVent/3600 * 1200 * (Ttop – Tout) [W/m²]
HTopAir = 0;

When all screens are stowed the temperature of the top-compartment is left out of the computations and the ventilation acts on the greenhouse air temperature.

HTopOut = 0;
HTopAir = fVent/3600 * 1200 * (Tair – Tout) [W/m²]

In both equations, fvent is the air exchange rate between the greenhouse and the outside air in m^3/hr and 1200 is the volumetric specific heat of air in J/(m^3 K).
Because every greenhouse has some leakage, fVent has a minimum value. This value is linearly dependent on the wind speed and is 0.3 m^3/(m^2 hr) per m/s of wind speed, with a minimum of 1.2 m^3/(m^2 hr). This means that only when the wind speed exceeds 4 m/s (a small breeze), the leakage of the greenhouse is supposed to grow with this 0.3 m^3/(m^2 hr) per m/s of wind speed increment.

In the above mentioned forced convection, the actual heat exchange is a linear relation between the temperature difference between the state variables. For free convection, the relation between the actual heat exchange and the temperature difference is in general not constant, but a function of the temperature difference itself. The general formula for heat exchange between a horizontal warm surface and a colder air volume above it reads:

HWarmCold = 1.7 * (Twarm – Tcold)^1.33 [W/m²]

This formula holds for large surfaces, like screens and covers, where the convective heat exchange around the cover is enlarged by the 1.2, due to the larger surface of the tilted pane.

For warm heating pipes the relation shows a very similar non-linearity. For round pipes, the sensible heat loss is described by

HPipeAir = Dpipe * Lpipe * 6.25 * (Tpipe – Tair)^1.32 [W/m²]

where Dpipe is the diameter of the pipe and Lpipe is the number of meters of pipe per m² greenhouse surface. For common greenhouses, the bottom heating system consists of pipes with a 51 mm diameter and there are commonly 10 of these pipes in an 8 meter trellis, meaning an average length of 1.25 m of pipes in the pipe rail circuit per m² greenhouse.

For the sensible heat release from the luminaires of artificial illumination, if applied in the computation, the same type of relation is used, and the term that takes account for the

surface (Dpipe * Lpipe) is set to a value dependent on the electrical lamp power. For a 100 W/m² HPS luminaire this surface is 0.02 m² per m² greenhouse and from that the model uses a linear relation between electric power and surface of luminaires.
Of course in reality, the efficiency and type of lamps will also determine the surface per W of installed lighting power. However, since this will only give some change in the equilibrium temperature at which the lamps release their heat and not in the total amount of heat released (because that is defined by the lamp characteristics such a fixed power-to-surface relation gives only a very small inaccuracy.

For small distributed surfaces, like the leaves of a crop, the free convective heat exchange coefficient is hardly affected by the temperature difference. This follows from the work of Stanghellini (1987). According to her work, the convective heat exchange from canopy leaves is more determined by local air velocities than by temperature differences. When the local air velocity around the leaves of for instance a tomato crop is supposed to be 0.1 m/s, the heat exchange from a leaf to the air is described by

HecLeafAir = 10 * LAI * (1+ (TLeaf-Tair)/140)   [W/(m² K)]

This dependency of the heat exchange is that small (1/140 times the temperature difference) that it is simply neglected.
In this formula LAI denotes the leaf surface in a specific crop layer per m² greenhouse surface.

Finally there is one more convectieve heat exchange that is not computed by the standard formulas for free convective heat exchange, which is the heat loss from the cover. This is strongly influenced by the wind speed. According to the work of Bot[1] this convective exchange is described by:

HecCovOut = 3.1 + 1.31 * Windsp   for wind speeds < 4 m/s   [W/(m² K)]

and

HecCovOut = 2.72 * Windsp0.8   for wind speeds > 4 m/s   [W/(m² K)]

With the three types of convective heat fluxes, sensible heat exchange processes from surface to air in the present model can be computed, after having used the appropriate parameters.

Apart from the free convective exchange between surfaces and air, there are also free buoyancy fluxes that describe the energy exchange from the one air compartment through a more or less porous surface (the screens) to another compartment. Just like the formerly mentioned fluxes, these bouancy fluxes are driven by temperature differences where a temperature difference dT results in an air flow of

$F\_T_1T_2 = 2.3e3 * (T_1 - T_2) * permeability$ [m³/s]

The permeability of the screens ranges from values around 0.9e-7 m^{-2} for tightly woven screens to 3e-5 m^{-2} for shade screens with a 40 % open. The permeability relates an air exchange to a pressure difference and the term 2.3e3 in the formula is the factor that translates a temperature difference to such a pressure difference.

With the buoyancy air flow through the screens as a function of the temperature difference across the screen, the heat exchange can be computed in a similar way as the heat exchange

1 Bot, G.P.A., 1983, Greenhouse Climate, from physical processes to a dynamic model. Proefschrift Wageningen University, Nederland

through leakage and vents.
So, for example, when using a single screen, the heat exchange from air to top through the screen can be computed by

HAirTop = 2.3e3 * (Tair - Ttop) * permeability * 1200 * (Tair – Ttop) [W/m²]

It is easy to see that this results in a quadratic relation between temperature difference and heat exchange through the screen. However, since the permeability is in general a small number for tight screens, the resulting energy flux is quite small as well.

Long wave radiative exchange

Besides the external fluxes and the free and forced convective heat fluxes, the model calculates radiative heat exchange in the wavelength region between 5 and 50 µm.

This long-wave radiative heat is exchanged between opaque surfaces in the greenhouse and between the greenhouse cover and the sky. In the current model, the number of opaque surfaces is maximal 15, namely the 14 real surfaces that can be distinguished plus the sky, which acts as a virtual surface. Since all surfaces in principle can radiate to each other, there are maximal 105 radiative heat fluxes to be determined (14+13+ … 2+1). However, in practical situations, the number of radiative fluxes will be a lot smaller. Double coverings are not widespread used, just like using all three screen layers. Moreover, surfaces at a certain point in the stack can be non-transparent for longwave radiation, which means that lower layer cannot 'see' all layers above them.

The general description of radiative heat transfer reads:

$$R_{S1S2} = \frac{\varepsilon_{S1}\, \varepsilon_{S2}\, F_{S1S2}\, A_{S1}}{1-\rho_{S1}\rho_{S2}\, F_{S1S2}F_{S2S1}}\ \sigma\,(T_{S1}^4 - T_{S2}^4)\ [W]$$

This equation, computing the energy exchanged from surface S1 to surface S2, is governed by the optical material properties of both surfaces and the geometrical configuration. The material properties are described by the emissivities ($\varepsilon S1$ and $\varepsilon S2$) and the infra-red reflection coefficients ($\rho S1$ and $\rho S2$). The geometrical configuration is defined by the radiation surface (A_{S1}) and the viewfactor, a number between 0 and 1 which gives the fraction of the hemisphere of the radiating surface that is occupied by the surface S2.

σ is the constant of Stefan-Boltzman (5.67e-8 W/K^4)

The nominator of this equation describes the primary radiative exchange between surface S1 and surface S2. The denominator takes account for the diminishing of the net radiation due to re-radiation by reflection of the destination surface. Obviously, when the reflection coefficient of one of the surfaces is zero, the denominator becomes 1 and re-radiation does not play a role.

When, however, the reflection of a surface is large, for example when using aluminized energy screens, re-radiation gives an important diminishing of the net radiative exchange. For this re-radiation, not only the viewfactor of surface S1 to surface S2 plays a role, but also the viewfactor from surface S2 to surface S1 (so telling how much of the hemisphere of S2 is occupied by S1).

When the area of the radiation surfaces is known and one of the viewfactors, the other viewfactor can easily be computed, using the reciprocity theorem

$$F_{S2S1} = F_{S1S2}\ A_{S1} / A_{S2} \qquad [-]$$

With this formula it can also be seen that R_{S2S1} is equal to R_{S1S2}, except for the sign, which will be opposite.

Going from the top of the greenhouse model downwards through the layers of the greenhouse, the radiative heat exchange between the cover and the sky is the first to be defined.

The sky by definition as a black body with a temperature Tsky, an emission coeeficient 1 and a reflection coefficient 0.

Therefore the radiative heat exchange between the cover and the sky is simply

$$R_{CovSky} = \varepsilon_{cov,up}\ F_{CovSky}\ A_{cov}\ \sigma\ (T_{cov}^4 - T_{sky}^4) \qquad [W]$$

The surface of the cover of a greenhouse is larger than the floor surface of the cover, but due to the repetitive tilted surfaces, the cover partly sees itself. This makes that the product FCovSky Acov equals 1 and the radiative exchange from the upper cover per m² of greenhouse surface is simply

$$R_{CovSky} = \varepsilon_{cov,up}\ \sigma\ (T_{cov}^4 - T_{sky}^4) \qquad [W/m^2]$$

The term $\varepsilon_{cov,up}\ \sigma$ will be called the radiative exchange coefficient (REC) and refers to the typical multiplication factor in a the computation of a radiative exchange.

Where the upper cover layer has only one upward flux, the second cover layer (if the greenhouse has a double cover) may have two upward fluxes. This depends on the transparency of the upper cover for infrared radiation. If the upper cover blocks all infrared radiation, the full hemisphere of the lower cover is occupied by the upper cover. Then the viewfactor of the lower cover to the sky becomes zero. However, in case the upper cover transmits, say, 40% of the infrared radiation, 60% of the hemisphere of the lower cover is occupied by the upper cover and 40% of the hemisphere is virtually occupied by the sky.

Such a break-down of the hemisphere of the different layers in the model into viewfactors to the designated surfaces in its hemisphere is carried out in the following piece of code

```
% Compute the radiativeExchangeCoefficients (REC), based on
% - infra red transmission (IRtrans)
% - the emission coeffients (epsUp and epsDo),
% - the reflection coefficients (reflUp and reflDo),
% = the surface of the radiation surface (surf)

for sIndex=2:15
  remainingHemishpere=1;
  for dIndex = sIndex-1:-1:1
    hemishpere = remainingHemishpere ;
    remainingHemishpere = hemishpere*IRtrans(dIndex);
    viewfactor=hemishpere - remainingHemishpere;  % this is  FS1S2
    otherViewfactor = viewfactor*surf(sIndex)/surf(dIndex); % this is  FS2S1
    nominator=epsUp(sIndex)*epsDo(dIndex)*viewfactor*surf(sIndex);
    denominator=1-reflUp(sIndex)*reflDo(dIndex)*viewfactor*otherViewfactor;
```

```
    REC = nominator/denominator * 5.67e-8;
  end
end
```

In this code, the 14 layers in the greenhouse model (numbered with index 2 through 15) and the sky layer (numbered with index 1) are indexed with the variable sIndex (the source index). Each surface may exchange radiative energy with the layers above it, indexed with the variable dIndex (the destination index) according to the viewfactor.

In the general description of radiative exchange, taking the re-radiation into account there is also the reciprocity viewfactor in the denominator.

Note also that for the source surface the upside reflection and emission coefficient are used and for the destination surface, the downside optical properties are used. For many materials the upside and downside properties will be the same, but especially for screens and for certain types of glass these may differ.

The piece of code defines the radiative exchange coefficient (REC) which by multiplication with the forth powered temperature difference (in Kelvin) yields the long wave radiative heat flux from any surface to every other surface.

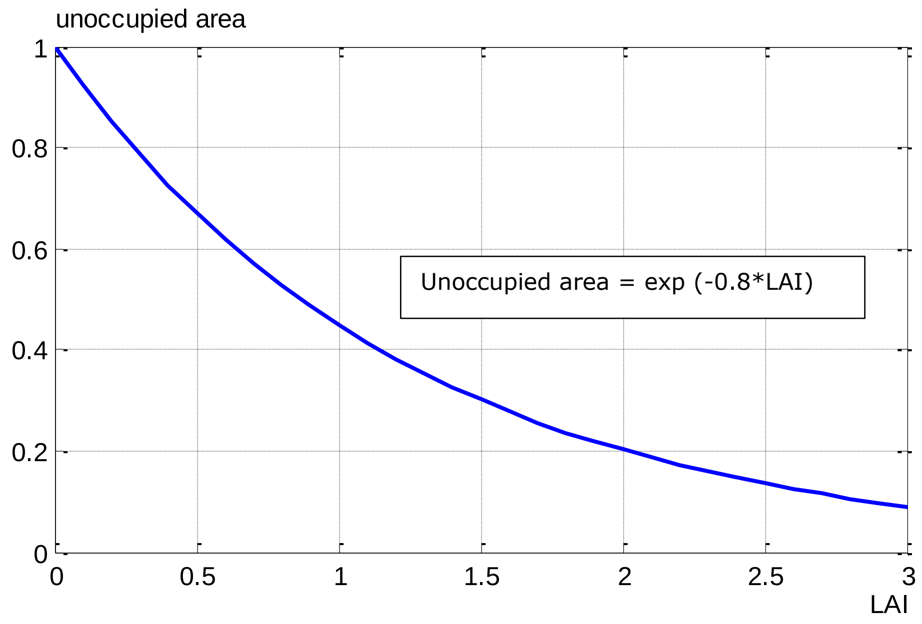
The surface of the majority of layers in the model is quite straightforward. For the sky, the screens and the floor the surfaces are 1 m^2 and for the covers the surfaces for radiative exchange are effectively 1.

For the heating pipes and lamps the surfaces are small. Lamps have a projected surface of about 0.02 m^2/m^2 greenhouse and an overhead and bottom heating system has a projected surface of about 0.06 m^2/m^2. A crop heating system has normally a smaller amount of pipes and pipes with a smaller diameter so it's projected surface is set to 0.02 m^2/m^2.

For the four crop layers the effective surface can be computed from the amount of leaves assumed to be represented by a layer in combination with the so called black-leaf-extinction coefficient. This extinction coefficient describes the rate with which surface is being occupied per unit of leaf surface. The integral of the black-leaf-extinction over a certain cumulative amount of leaves shows the extinction of 'unoccupied area'.

The black-leaf-extinction coefficient of high wire vegetable crops like cucumber or tomato ranges between 0.75 and 0.85.

Assuming an extinction coefficient of 0.8, the extinction of unoccupied area going down into the crop starting at Leaf Area Index 0 until LAI=3 at the bottom follows the curve shown in the figure below.



Suppose the 4 crop layers in the model are used to describe an even distribution of leaf surface of the crop. This makes that each crop layer represents 0.75 m² of leaf area. According to the formula, a cumulative leaf area of 0.75 m² changes the unoccupied area from exp (-0.8*0) = 1 to exp (-0.8*0.75) = 0.55, which means that 45% of the area is blocked by this 0.75 m² of leaf-package. Apparently the 'transmissivity' of this package is 55%.

The next 0.75 m² of leaf-package does the same and, indeed, 4 subsequent transmissions of 55% yields a remaining 'unoccupied area' of 9%, which is the end-point of the curve.

So, the IR transmission of each crop layer in this particular case is 0.55 and the effective surface in each layer is 0.45 m². This is obviously smaller than the 0.75 m² of leaves that are actually in the leaf-package, which is caused by the mutual masking of leaves in a canopy stack.

Although different crop architectures will result in different black leaf extinction coefficients, the current model uses this 0.8 for all crops, but does vary in the amount of leaf surface per crop layer (see Crop parameters).

Energy balance and iteration

With the above described formulas to compute the fluxes, the energy balance for each of the states in the model can be defined. The iterative procedure to determine the equilibrium temperature is based on the straightforward euler integration method for numerical integration after assigning an equal heat capacity to all the states (1000 J/K). The iteration is stopped when for all states the sum of the incoming and outgoing energy fluxes approaches 0 (<0.5 W). This means that all state variables have reached their equilibrium temperature under the given boundary conditions.

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Parameters for the light sources

If artificial illumination is used, the model has different light sources.

The amount of light is parametrized by the PAR flux denisity in µmol/m² s. For the High Pressure Sodium lamps, an efficiency of 1.75 µmol/J is used. This is a high efficiency, holding only for new and modern HPS-systems.

For LED illumination three efficiencies are mentioned. 2 µmol/J is a good performing system. 2.7 µmol/J denotes the currently highest commercially available system and the 3 µmol/J is expected to become available in near future.

After combining the user-defined light intensity with the PAR-efficiency, expressed in µmol/J, a light intensitiy becomes equivalent with an electricity consumption. The electricity consumption of a light source results in a short wave energy output in the form of PAR and NIR radiation, but it also heats up the lighting equipment. Therefore this lighting equipment becomes a warm body which will lose it's energy by convection and thermal radiation. Convective radiation is released to the greenhouse are and the (long wave) thermal radiation is send to all non-transparent objects in the greenhouse. Of course this longwave exchange is subject to view factors and emission coefficients (see Radiative exchange)

The parameters that translate the PAR intensity to electricity consumption and from there to shortwave radiation and heating of the luminaires is stated in the table below.

Illumination type	efficiency (µmol/J)	Fraction converted to			Light interception per 100 µmol/(m² s)
		PAR	NIR	Thermal	
LED with 2.0 µmol/J eff.	2.00	0.46	0	0.54	1.5%
LED with 2.7 µmol/J eff.	2.70	0.62	0	0.38	1.5%
LED with 3.0 µmol/J eff.	3.00	0.7	0	0.30	1.5%
HPS Lichting (1.75 µmol/J)	1.75	0.41	0.20	0.39	1%

Obviously, when increasing the intensity of the illumination, the amount of luminaires will grow, which will result in a larger amount of warm objects in the greenhouse.

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Parameters for the screens

The user can choose for the simulation from none up till three screens. If the user chooses to simulate two or three screens, then the position of the marked screens in the screens-pane is also the relative position of the screens in the greenhouse.

The following screens can be chosen

FOIL SCREEN

This screen is simply an E.V.A. film.

LUXOUS 1347 FR

This is a semi-transparent energy saving screen that can be used both during day and night.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/luxous/luxous-1347-fr

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LUXOUS_1547_D_FR

This is a semi-transparent energy saving screen that can be used both during day and night.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/luxous/luxous-1547-d-fr

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HARMONY_2947_FR

This is a screen that can be used both for shading during daytime and energy saving at night.

Detailed information:

http://www.ludvigsvensson.com/Site/ProductCatalog/Handler/ClimateScreensPDF.ashx?productID=4db0909f-d3cb-4b57-ac28-49e774b73da4&websiteID=0417fe15-2dc7-4623-a2a0-57c941eb989b&languageID=aec05dc8-59c6-41ea-9dc2-1dc8c84858db

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HARMONY_5047_FR

This is a screen that can be used both for shading during daytime and energy saving at night.

Detailed information:

http://www.ludvigsvensson.com/Site/ProductCatalog/Handler/ClimateScreensPDF.ashx?productID=5fe5cbe9-4e78-4150-9ad0-a05269752689&websiteID=9d9a2d65-0506-45a7-be47-07ad2a99e8e0&languageID=a4708dfc-2a48-44de-8fad-bb7320bd3c50

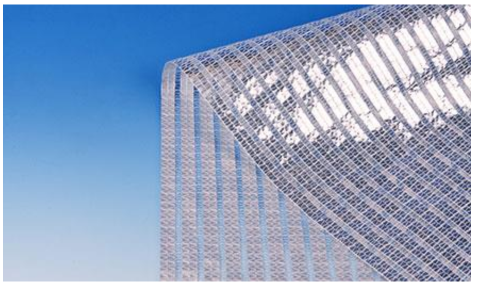
HARMONY_7247_FR

This is a screen that can be used both for shading during daytime and energy saving at night.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/harmony/harmony-7247-fr

TEMPA_6965FR



This is a screen that can be used both for shading during daytime and energy saving at night.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/tempa/tempa-6965-fr

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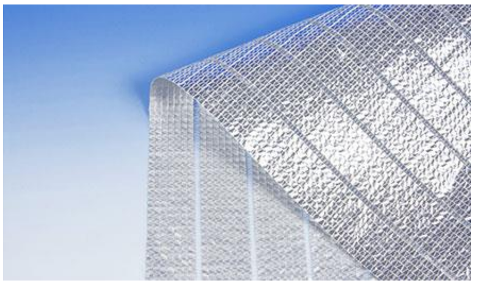
TEMPA_8570_FR



This is a screen that can be used both for shading during daytime and energy saving at night.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/tempa/tempa-8570-fr

OBSCURA_9950_FR

This is a darkening screen that also can be used for energy saving purposes.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/obscura/obscura-9950-fr-w

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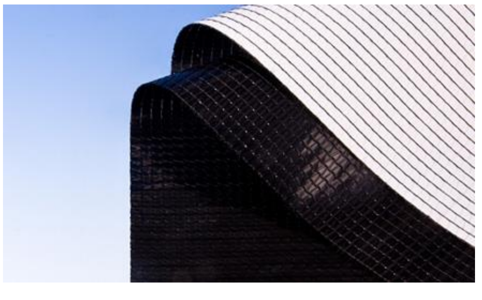
OBSCURA_10070_FR_WB+B



This is a darkening day length control screen that can also be used for energy saving purposes.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/obscura/obscura-10070-fr-wb-b

OBSCURA_10075_FR_AB+B

This is a darkening day length control screen that also gives a large energy saving due to the aluminium

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/obscura/obscura-10075-fr-ab-b

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HARMONY_2515_O_FR

This is an open shading screen that can also be used at night for energy saving purposes.

Detailed information:

https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwin2KGT2vfOAhVoLMAKHaL9Bp0QFggeMAA&url=http%3A%2F%2Fwww.ludvigsvensson.com%2FSite%2FProductCatalog%2FHandler%2FClimateScreensPDF.ashx%3FproductID%3Dc269a32f-1bbe-407d-828a-b3ef99c7a417%26websiteID%3D9d9a2d65-0506-45a7-be47-07ad2a99e8e0%26languageID%3Da4708dfc-2a48-44de-8fad-bb7320bd3c50&usg=AFQjCNHx7bXLnzAKKVRfCNS0UvZyIHpn8g&sig2=DRZo-sKOyoomR0Hti6tlUQ&bvm=bv.131783435,d.d2s

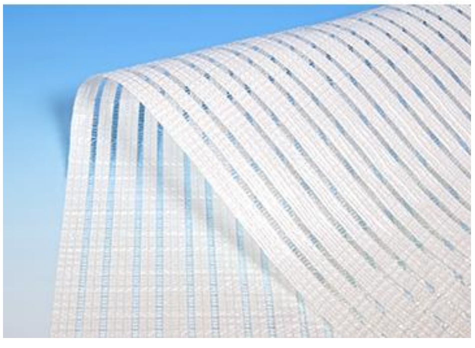
HARMONY_4515_O_FR

This is an open shading screen that can also be used at night for energy saving purposes.

Detailed information:

http://www.ludvigsvensson.com/Site/ProductCatalog/Handler/ClimateScreensPDF.ashx?productID=5eb71ba9-4b0e-4fd1-928c-0effbf24fc25&websiteID=9d9a2d65-0506-45a7-be47-07ad2a99e8e0&languageID=a4708dfc-2a48-44de-8fad-bb7320bd3c50

HARMONY_5220_O_FR



This is an open shading screen that can also be used at night for energy saving purposes.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/harmony/harmony-5220o-fr

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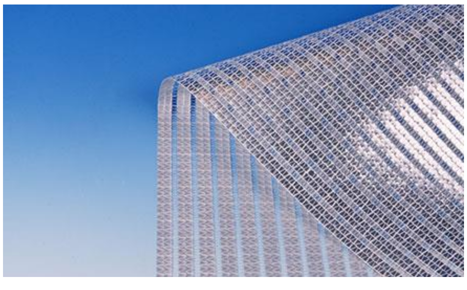
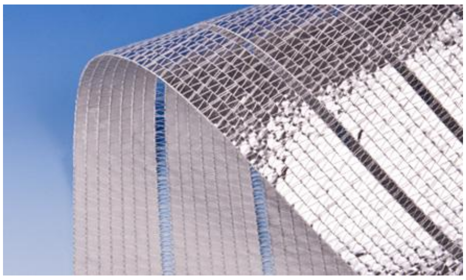
SOLARO_6827_O_FR



This is an open shading screen that can also be used at night for energy saving purposes.

Detailed information:

http://www.ludvigsvensson.com/climatescreens/products/climate-screens/solaro/solaro-6827-o-fr

SOLARO 8430 O FR	
	This is an open shading screen that can also be used at night for energy saving purposes. Detailed information: http://www.ludvigsvensson.com/climatescreens/products/climate-screens/solaro/solaro-8430-o-fr [Back]
FCLEAN	This screen is an ETFE film
PERF FCLEAN (10x10)	This is a highly transparent PE film with 10x10 mm perforations.

For each screen, the user can choose from a list of commercial screens normally used for energy saving purposes in greenhouses. For all screens in the list, the optical and aerodynamic parameters have been determined in the Wageningen UR Greenhouse horticulture Lightlab (http://www.wur.nl/en/show/Help-with-important-choice-for-the-best-covering-material.htm)

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Crop parameters

The user can choose for a simulation with different crops. The crops differ with respect to their transpiration rate and with respect to the division of leaf surface into the 4 crop layers described by the model. In all cases, the crop transpiration is computed from relations that describe the behaviour of the stomatal resistance for moisture transport and that compute the driving force for the moisture transport. This driving force is the difference in moisture content in the leaf cavities and the moisture content of the greenhouse air.

The stomatal behaviour is modelled by a simple formula that yet gives a very close match between observed and computed transpiration rates in tomato, especially during the low-light conditions for which the Radiation monitor was designed.

Unfortunately, Wageningen UR does not have ready to use detailed data on the transpiration rate of other crops so, for the other crops, simple multiplication factors compared to tomato are used. These multiplication factors are listed below.

Crop	Transpiration as a factor compared to tomato
Tomaat	1
Komkommer	0.85
Paprika	0.75
Roos	0.95
Gerbera	0.9

The different crops do not only have different transpiration factors compared to tomato, but also all have their typical Leaf area index. The table below shows which leaf surfaces in each layer per m2 greenhouse area are being used

Crop	LAI per layer
Tomato	0.75 - 0.75 -0.75 -0.75
TomatoHT	0.15 - 0.95 -0.95 -0.95
Cucumber	0.75 - 0.75 -0.75 -0.75
CucumberHT	0.15 - 0.95 -0.95 -0.95
Sweet pepper	1 - 1 - 1 – 1
Rose	0.1 – 0.9 – 0.9 – 0.9
Gerbera	0.1 – 0.8 – 0.8 – 0.8

For the two flower crops, the top layer has only a small surface. This top layer represents the flowers and flower buds. These parts of the crop transpire much less than leaves so for the top layer of these crops, the resistance to transpiration is increased by a factor 2.5 compared to the transpiration resistance of leaves.

The crop-descriptions TomatoHT and CucumberHT refer to Tomato and Cucumber crops with a different distribution of the leaf surface over the 4 layers. In the 'HT'-cases the top layer describes the temperature of the top 0.15 m² of the crop which is considered to be the head of the crop.

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Wageningen UR Greenhouse Horticulture

Wageningen UR Greenhouse Horticulture is dedicated to innovating for and with the greenhouse horticulture sector. In collaboration with the business and scientific communities and the government, we analyse issues relating to operational management and cultivation and translate them into application-oriented research and innovation procedures.

Wageningen UR Greenhouse Horticulture has locations in Wageningen and Bleiswijk. The Bleiswijk location is in the heart of the municipality of Lansingerland, the second most important greenhouse horticulture location in the Netherlands. This provides a direct communication with both the professional field and the scientific community. It enables to take advantage of vast professional and scientific knowledge, expertise, and facilities.

The research facilities are unlike any in the world, with greenhouses for research into sustainable crop protection, experimental energy-saving greenhouses, and measurement set-ups for research into greenhouse materials and early signalling of crop stress. The Bleiswijk location has two Innovation and Demo Centres on the Energy and Water Treatment grounds.

See for further information: http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/Wageningen-UR-Greenhouse-Horticulture/About-us.htm

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The research program Kas Als Energiebron

The research program Kas Als Energiebron (Greenhouse as source of Energy) aims on a drastic decrement of the fossil fuel consumption of the Dutch Horticultural sector.
The project is co-funded by the Ministry of Economic affairs and representatives of the Dutch horticultural sector.

KAS ALS ENERGIEBRON

See for further information: https://www.kasalsenergiebron.nl/

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Anthura is expert op het gebied van orchideeën en anthurium. Met een focus op deze productgroepen is Anthura uitgegroeid tot toonaangevende leverancier van wereldformaat, met afzet van jong plantmateriaal in meer dan 70 landen. Met een continue ontwikkeling van duurzame, nieuwe rassen en producten is Anthura gericht op de lange termijn en waarborgt zij hiermee continuïteit.

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Beekenkamp

Beekenkamp: collaboration for the best result

Three spheres of activity, three expertises, three companies that join forces. Exactly that is the Beekenkamp Group. A family business consisting of Beekenkamp Plants, vegetables & ornamentals, Beekenkamp Verpakkingen (Packaging) and Deliflor Chrysanten (Chrysanthemums).

Since its foundation in 1951, the group has developed into a company that employs 2200 people worldwide, that produces over 1.7 billion young plants per year and has a total greenhouse area of almost 80 hectares..

For more information: https://beekenkamp.nl/en

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Biobest

For more information:

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Biotamax

For more information:

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Bonar is the leading producer & supplier of high performance technical textiles.

For more information: http://www.bonar.com/europe/be/home/

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Floricultura

Orchids are our passion. Searching for more beautiful, productive and distinctive varieties for our customers: that's the driving force behind the people at Floricultura.
Since 1933 our company has been a specialist in breeding, propagation and initial development of Phalaenopsis, Miltonia, Dendrobium, Cymbidium and other varieties.

As the market leader in orchid propagation material, we supply professional growers worldwide with many tens of millions of plants each year, to be grown into cut flowers and pot plants. We achieve this by having our own nurseries in the Netherlands, the USA and Brazil.

Our success is founded on extensive research, a unique gene bank and many years of expertise. At our research and breeding locations in the Netherlands, we ensure both breadth and depth in our range of orchids. For every grower, for every climate zone and for every kind of consumer. New products are only introduced to the market if they satisfy the very highest quality requirements.

We care about growers' results

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Hoogendoorn Growth Management

Hoogendoorn is known as the most innovative supplier of process automation systems in the horticultural industry. For almost 50 years, they have been striving towards the optimal greenhouse climate, increasing crop yields and managing costs and risks in greenhouse horticulture. Their automation solutions contribute to the sustainable use of water and energy and are available in several languages. Hoogendoorn systems are supported with user training, 24/7 helpdesk and reliable maintenance service. These services are provided via their local offices and worldwide partner network.

Hoogendoorn products and services comprise:
- The next generation iSii process computer
- iSii compact: Irrigation and climate control system
- Nomad: Real-time path and labor registration systems
- Inside and outside sensors
- Aquabalance: Weighing scale for on line crop transpiration measurement with intelligent software
- Service & support
- Training: on site and online

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Ludvig Svensson

Innovative climate screen solutions for greenhouse cultivation

Creating better climates for plants and businesses!

Svensson is the pioneer and world leader in climate control and energy efficiency through textile-based solutions. The business started in the 1970s with a vision to transform and improve conditions for the professional cultivation of vegetables and flowers in greenhouses. Svensson has since revolutionized the industry with a range of innovative solutions.

Today, our functional climate screens control humidity, temperature and UV radiation according to requirements, creating excellent conditions for better and greater production in greenhouses all over the world.

For more information visit: http://www.ludvigsvensson.com/climatescreens/about-us

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Oerlemans Plastic BV

Oerlemans Plastics is a manufacturer of flexible synthetic packaging and film products.
We continually develop new film and packaging concepts for the horticultural, packaging, retail and other industries.
Our products are sold in more than 30 countries worldwide. Satisfaction, quality and a profitable result are key elements in the solutions we offer our customers. We control all logistical operations ourselves, thereby offering the best possible service

https:/www.oerlemansplastics.nl

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PB Techniek

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Plantion

Plantion is a lively market place for florists, commercial gardeners and retailers!

Every day, in the early morning florists buy fresh, wonderfully perfumed products for their shops at the clock auction. Commercial gardeners come to the Green Centre for a unique assortment of trees and shrubs. And retailers can buy beautiful flowers, plants and accessories in the Wholesale Centre. Plantion is very comprehensive, highly professional but also has a pleasant atmosphere and is well organised. Our service is customer-focussed and our approach to our customers is friendly. Growers and buyers are not merely a number to us, but have a real name and face. That is how we really like to work, you too?

Plantion lies in the town of Ede along the A12, in a great central location that's easy to find. Come and visit us!

http://plantion.nl/?language=3

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Priva

We are Priva.
We make products and supply services for process management and climate control in non-residential buildings, in horticulture and in industry. An international family business with roots in the soil of Westland. This is obviously fertile soil, because we have grown to become a global company. A company with sites and training centres on every continent, from China to Canada and from Mexico to Scandinavia. And with our dealer and partner network, we are represented in more than 100 countries. This means we are close to our customers, in the same time zone: we know their business, and we speak their language! And that, of course, makes everything easier!
Our headquarters is the Priva Campus in De Lier (Netherlands). Here we devise and produce innovative solutions for sustainable climate control and process management in the horticulture industry and the built environment. With an R&D department of 120 super-smart colleagues, we are constantly working on improving existing products and on coming up with new ideas for our customers.

More information: http://www.privagroup.com/en/

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Rabobank Westland

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Rabobank ZH Midden

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Revaho/Netafim

Netafim, founded in 1965 in Israel, is the global leader in smart irrigation solutions and turnkey greenhouse horticultural projects. With 28 subsidiaries, 17 factories and 6000 employees worldwide, Netafim delivers innovative solutions in over 110 countries.
Next to this, Netafim also provides diverse state-of-the-art solutions for agriculture, landscaping and mining.
All our solutions are accompanied by expert agronomic, technical and operational support.
Netafim's market-leading solutions are helping the world to **grow more with less**!

Netafim, opgericht in 1965 in Israël, is marktleider in slimme irrigatieoplossingen en turn-key tuinbouwprojecten. Met wereldwijd 28 verkoopkantoren, 17 fabrieken en 6000 medewerkers leveren we onze innovatieve producten en diensten in meer dan 110 landen.
Hiernaast leveren we ook verschillende hightech oplossingen voor de landbouw, landschap architectuur en mijnbouw. Al meer dan 50 jaar helpen onze toongevende oplossingen de wereld om meer te telen met minder!

For more information: http://www.netafim.com/greenhouse

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Royal Brinkman

Royal Brinkman is a supplier, consultant and installer for the professional horticulture industry. In view of its global specialisation in seven disciplines, Royal Brinkman is capable of providing the best possible services for customers in the field of crop rotation, crop care, crop protection & disinfection, packaging & design, mechanical equipment, technical projects and service articles.

Innovations are developed according to the Lean Innovation method, as a result of which Royal Brinkman and the partners, suppliers, knowledge institutions and customers with which it cooperates can respond optimally to questions and market requirements. In addition to personal contact via specialists and local offices, Royal Brinkman is strongly committed to the field of online marketing & sales.

With webshops and online quotation-desks in more than 14 languages, Royal Brinkman has an extensive global reach.

For more information: www.royalbrinkman.com/

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Valto BV

Valto is an innovative, Dutch family company dedicated to all aspects of natural crop protection. Our goal is to bridge the gap between growers all over the world on the one side and science on the other. This approach has enabled us to develop products that have proven to be highly effective. This has been confirmed not only by the many growers who use them; it has also been scientifically proven in independent tests and analyses performed on a regular basis.

For more information: http://www.valto.nl/en

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VB Group

The ideal climate for your corp.

Which climate equipment is best for your greenhouse? VB Climate, part of the VB Group, advices and installs.
As an international supplier we have knowledge of the newest techniques all over the world.

VB Climate provides turn-key solutions including cooling, screening, heating and venting.
our knowledge and experience results in innovative solutions, tailored to local conditions.

And in order to contribute to a sustainable horticulture we can add all kind of alternative and sustainable energy sources.

For further information: http://www.vb-group.nl/en/greenhouses

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