Research Article

Modelling and Simulation for Energy Production Parametric Dependence in Greenhouses

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Greenhouses crops in Italy are made by using prefabricated structures, leaving out the preliminary study of optical and thermal exchanges between the external environment and the greenhouse, dealing with heating and cooling and the effects of air conditioning needed for plant growth. This involves rather significant costs that directs the interest of designers, builders, and farmers in order to seek constructive solutions to optimize the system of such emissions. This work was done by building a model of gases using TRNSYS software, and these gases then have been checked for compliance. The model was constructed considering an example of a prefabricated greenhouse, located in central of Italy. Aspects of the structural components, and thermal and optical properties are analyzed in order to achieve a representation of reality.

1. Introduction

The aim of this study is to test the response of the software TRNSYS simulation of climate parameters in a greenhouse. To create a template for:

- (i) detailed design of structures,
- (ii) optimizing resources,
- (iii) verifying the use of new energy systems for agricultural activities [1–3].

To simulate the greenhouse, several studies have been proposed in order to obtain forecasts values or simulations of influential variables for protected crops, such as ventilation [4, 5], water temperature for hydroponic systems [6], control of CO₂ for the carbon fertilization [7, 8], moisture budget [9], climate control [10], and heat exchange [11]. Recently,

the thermal behavior of the greenhouses was studied using dynamic thermal simulation tool, TRNSYS 15.1. [12, 13].

Suppose that one has created a model that includes all greenhouse influential variables on microclimate. Values are obtained for climatic parameters representative of reality by allowing the search for optimal solutions for the use of resources [14].

Creating a greenhouse model in the software, one can simulate constructive solutions or air conditioning. One can also create new components to include models that simulate as closely as possible the biological activities of plants.

2. Preliminary Remarks

2.1. Exchange of Heat

The climatic parameters affecting the growth of greenhouse plants are [15]:

- (i) radiation entering the greenhouse in the ultraviolet band (290 to 380 nm), visible (380 to 760 nm) and near infrared (760–3000 nm),
- (ii) temperature of air, soil and plants,
- (iii) air humidity,
- (iv) air composition (particularly the concentration of CO₂).

Solar radiation inside the greenhouse is less than the outer coating material which reflects and absorbs solar radiation; one also needs a ventilation system that ensures the movement of air between the plants and facilitates the transpiration; the lower is the air movement, and the smaller is the concentration gradient of CO₂.

One needs to assess the detailed exchange of energy between internal and external and to have accurate values of climatic parameters in the greenhouse. It is necessary to study the temperatures that influence the thermal freight exchange [16]:

- (i) air temperature,
- (ii) soil temperature (or substrate for soilless),
- (iii) plants temperature,
- (iv) temperature of the greenhouse cover.

The flow of heat in the greenhouse is a function of time and is calculated using (2.1) which represents the heat balance [17]

$$\frac{\partial Q(t)}{\partial t} = q_{\text{ent}}(t) - q_{\text{usc}}(t) + W_{\text{int}}, \quad (2.1)$$

where Q : flow thermal, t : time, q_{ent} : heat flows in, q_{usc} : heat flows out, and W_{int} : thermal power in the greenhouse.

C_p : heat capacity of the greenhouse, the heat balance of systems (2.1)

$$C_p \frac{\partial T}{\partial t} = q_{\text{ent}}(t) - q_{\text{usc}}(t) + W_{\text{int}}. \quad (2.2)$$

2.2. Thermal Balance

To calculate the heat balance in emissions is necessary to examine the individual energy input [18]:

- (1) solar radiation transmittance and reflectance of the cover to the incident radiation,
- (2) heat transfer, conduction, convention, and radiation,
- (3) condensation heat,
- (4) heat of evapotranspiration,
- (5) loss of heat of ventilation.

2.2.1. Solar Radiation

The amount of heat which determines the solar radiation [19] depends on:

- (i) radiation incident to the ground,
- (ii) orientation of the greenhouse,
- (iii) type of structure,
- (iv) absorption and reflection of the coating material,
- (v) share, size, and position of the opaque structure,
- (vi) dust on the cover,
- (vii) cover condensation.

The incident radiation to the ground, with clear skies, [20] can be calculated with the following relations:

$$R_b = \text{direct radiation to the ground} = R_e \tau_b \cos \theta_z \text{ [W/m}^2\text{]},$$

$$R_d = \text{diffuse radiation to the ground} = R_e \tau_d \cos \theta_z \text{ [W/m}^2\text{]},$$

$$R_g = \text{global radiation to the ground} = R_b + R_d \text{ [W/m}^2\text{]},$$

where R_e = outer radiation $\text{[W/m}^2\text{]}$, $\cos \theta_z$ = cosine zenith angle = $\sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega$, ϕ = local latitude $[\circ]$.

Inclination of the sun = $\delta = 23.45 \cdot \sin \cdot [360/365 \cdot (284+n)]$ $[\circ]$, hour angle $\omega = (360/24) \cdot (12 - h)$ $[\circ]$, τ_b = transmissivity of the atmosphere [21] to the direct radiation = $A_0 + A_1 \times e^{-k/\cos \theta_z}$, τ_d = transmissivity of the atmosphere [21] to the diffuse radiation = $0.271 - 0.294 \tau_b$, $A_0 = [0.4237 - 0.00821(6 - A)^2][1 + 0.03 \sin(\pi \text{ Error!})]$, $A_1 = [0.5055 + 0.00595(6.5 - A)^2][1 + 0.01 \sin(\pi \text{ Error!})]$, $K = [0.2711 + 0.01858(2.5 - A)^2][1.01 - 0.01 \sin(\pi \text{ Error!})]$, n = julian day, h = hour days [h], and A = altitude [km].

If the surface is inclined, there will be two angle: Z = inclination of the surface normal with respect to zenith and ψ = angle between the horizontal projection of the surface normal and the south.

The angle between the direction of the sun and the surface normal is

$$\begin{aligned} \cos I = & \sin \lambda \sin \delta \cos Z - \cos \lambda \sin \delta \sin Z \cos \psi + \cos \lambda \cos \delta \cos \omega \cos Z \\ & + \sin \lambda \cos \delta \cos \omega \sin Z \cos \psi + \cos \delta \sin \omega \sin Z \sin \psi. \end{aligned} \quad (2.3)$$

The components of radiation are [22]

$$R_b I = \text{direct radiation on inclined surface} = R_e \tau_b \cos I,$$

$$R_d I = \text{diffuse radiation on inclined surface} = R_e \tau_d \cos I.$$

Radiation throughout the cover is

$$R_b I = \text{direct radiation} = R_e \tau_b \text{ transmittance } (I),$$

$$R_d I = \text{diffuse radiation} = R_e \tau_d \text{ transmittance } (I).$$

To calculate the solar transmittance, I must have the total reflectance of the surface [23]. The reflectance is calculated from the angle of radiation and the angle of refraction of the surface

$$\frac{n_1}{n_2} = \frac{\sin \theta_r}{\sin \theta_i}, \quad (2.4)$$

where s = thick coerture, n = refracting index, k = coefficient absorption, and (ad es.glass: $n = 1.526$ and $K = 0.032 \text{ mm}^{-1}$)

The refractive index of air is approximately 1 [24]; there is $n_2 = n$ (refractive index of the second half): θ_r = refraction angle = $\arcsin(\sin \theta_i / n)$, θ_i : incidence angle of solar radiation as a function of latitude and exposure greenhouse [25].

$$\text{Surface reflectance} = r_{\perp} = \sin^2(\theta_r - \theta_i) / \sin^2(\theta_r + \theta_i).$$

$$\text{Surface reflectance} = r_{\parallel} = \tan^2(\theta_r - \theta_i) / \tan^2(\theta_r + \theta_i).$$

$$\text{Total surface reflectance} = r = I_r / I_i = (1/2)(r_{\perp} + r_{\parallel}).$$

The transmittance value of the perpendicular component whereas the only loss by reflection

$$\tau_{\perp} = (1 - r_{\perp})^2 \sum_{n=0}^{\infty} r_{\perp}^{2n} = \frac{(1 - r_{\perp})^2}{(1 - r_{\perp}^2)} = \frac{1 - r_{\perp}}{1 + r_{\perp}}. \quad (2.5)$$

Transmittance to the parallel component whereas the only losses for reflection

$$\tau_{\parallel} = \frac{1 - r_{\parallel}}{1 + r_{\parallel}}. \quad (2.6)$$

Transmittance with the only losses for global reflection

$$\tau_r = \frac{1}{2} \left[\frac{1 - r_{\perp}}{1 + r_{\perp}} + \frac{1 - r_{\parallel}}{1 + r_{\parallel}} \right], \quad (2.7)$$

whereas the overall transmittance only losses for absorption

$$\tau_a = e^{(-K \cdot s) / \cos \theta_r}. \quad (2.8)$$

The transmittance, reflectance, and absorbance of a greenhouse, with the losses by reflection and absorption are determined

$$\begin{aligned}
 \tau_{\parallel} &= \frac{\tau_a(1-r_{\parallel})^2}{1-(r_{\parallel}\tau_a)^2} = \tau_a \cdot \frac{1-r_{\parallel}}{1+r_{\parallel}} \cdot \frac{1-r_{\parallel}^2}{1-(r_{\parallel}\tau_a)^2} \cong \tau_a \cdot \frac{1-r_{\parallel}}{1+r_{\parallel}}, \\
 \tau_{\perp} &\cong \tau_a \cdot \frac{1-r_{\perp}}{1+r_{\perp}}, \\
 \tau &= \frac{1}{2}(\tau_{\parallel} + \tau_{\perp}) \cong \frac{1}{2} \left(\tau_a \cdot \frac{1-r_{\parallel}}{1+r_{\parallel}} + \tau_a \cdot \frac{1-r_{\perp}}{1+r_{\perp}} \right), \\
 \tau &\cong \tau_a \cdot \frac{1}{2} \left(\frac{1-r_{\parallel}}{1+r_{\parallel}} + \frac{1-r_{\perp}}{1+r_{\perp}} \right) \cong \tau_a \cdot \tau_r.
 \end{aligned} \tag{2.9}$$

The global transmittance is

$$\tau \cong \tau_a \cdot \tau_r. \tag{2.10}$$

The reflectance greenhouse is [26]

$$\rho_{\parallel} = r_{\parallel} + \frac{(1-r_{\parallel})^2 \tau_a^2 r_{\parallel}}{1-(r_{\parallel}\tau_a)^2} = r_{\parallel}(1 + \tau_a \tau_{\parallel}). \tag{2.11}$$

The absorbency is

$$\begin{aligned}
 \alpha_{\parallel} &= (1-\tau_a) \left(\frac{1-r_{\parallel}}{1-r_{\parallel}\tau_a} \right), \\
 \alpha_{\perp} &= (1-\tau_a) \left(\frac{1-r_{\perp}}{1-r_{\perp}\tau_a} \right), \\
 \alpha &= \frac{1}{2}(\alpha_{\parallel} + \alpha_{\perp}).
 \end{aligned} \tag{2.12}$$

The transmittance of the diffuse radiation is assumed to be equal to the transmittance of direct radiation with $II = 60^\circ$ m.

With the overcast sky [27], one can estimate the average daily radiation ($\text{J}/\text{m}^2\text{d}$) that reaches the earth's surface in a certain place (see Table 1).

Definition:

N_o : the length of day

$$N_o = \frac{2}{15} \cdot \arccos(-tg\phi \cdot tg\delta), \tag{2.13}$$

Table 1: The coefficient depends on a number of factor [30].

	α_i (W/m ² K)	In dependency of:
Inside the greenhouse	4–30	Wind Speed ($V_{\text{vento}} < 10 \text{ m/s}$ $3.85 V_{\text{vento}}$)
Outside the greenhouse	2–5	Heating System Temperature coverage
External heating pipes (air)	4.5–9	Pipe diameter Pipe temperature
Internal heating pipes (water)	400–4830	Water speed Pipe diameter

N : hours when the sun is actually visible on the horizon. The ratio N/N_o is called for sunshine or daylight on. The daily global radiation is related all'eliofania on the report of Angstrom

$$\frac{R_g}{R_o} = A + B \frac{N}{N_o},$$

$$R_o = \frac{1367 \cdot 3600 \cdot 24}{\pi} \cdot \left(1 + 0.033 \cdot \cos \frac{360 \cdot n}{365}\right) \cdot \left(\cos \phi \cdot \cos \delta \cdot \sin \omega_s + \frac{\pi \cdot \omega_s}{180} \cdot \sin \phi \cdot \sin \delta\right), \quad (2.14)$$

where ω_s is the hour angle at sunset

$$\cos \omega_s = -\tan \phi \cdot \tan \delta, \quad (2.15)$$

A and B coefficient of the place (see [28]).

The components of direct and diffuse radiation on an inclined surface can be calculated [29] as a function of I and Q multiplied by the transparency measured at normal incident radiation (Table 1). The components of radiation are:

$$R_b I = \text{direct radiation on the inclined surface} = R_e \tau_b \cos I,$$

$$R_d I = \text{diffuse radiation on the inclined surface} = R_e \tau_d \cos I.$$

2.2.2. Thermal Exchange

A contribution to the heat of the greenhouse is the thermal exchange between inside and outside [31].

Heat Conduction

$$Q = \frac{\lambda}{s} \cdot S \cdot (T_1 - T_2), \quad (2.16)$$

where Q = heat [W], s = thick [m], S = surface [m²], T_1 = inside temperatures of the surface wall, and T_2 = outer temperature surface of the wall.

If the surface S is composed with more elements, the flow through each element is constant

$$\begin{aligned}
 Q &= \frac{\lambda_1}{s_1} \cdot S \cdot (T_i - T_2) \Rightarrow Q \cdot \frac{s_1}{\lambda_1} = S \cdot (T_i - T_1), \\
 Q &= \frac{\lambda_2}{s_2} \cdot S \cdot (T_1 - T_2) \Rightarrow Q \cdot \frac{s_2}{\lambda_2} = S \cdot (T_1 - T_2), \\
 &\vdots \\
 Q &= \frac{\lambda_n}{s_n} \cdot S \cdot (T_{n-1} - T_e) \Rightarrow Q \cdot \frac{s_n}{\lambda_n} = S \cdot (T_{n-1} - T_e),
 \end{aligned} \tag{2.17}$$

adding

$$\begin{aligned}
 Q \cdot \left(\frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} + \dots + \frac{s_n}{\lambda_n} \right) &= S \cdot (T_i - T_e), \\
 Q &= \frac{1}{(s_1/\lambda_1 + s_2/\lambda_2 + \dots + s_n/\lambda_n)} \cdot S \cdot (T_i - T_e),
 \end{aligned} \tag{2.18}$$

to $K_t = 1/(s_1/\lambda_1 + s_2/\lambda_2 + \dots + s_n/\lambda_n)$ [W/m² K] thermal conductance

$$Q = K_t \cdot S \cdot (T_i - T_e). \tag{2.19}$$

Heat Convection

$$Q = \alpha_i \cdot S \cdot (T_{\text{fluido}} - T_{\text{parete}}), \tag{2.20}$$

where Q : heat convection, α_i : coefficient convective exchange, S : surface, and T : temperature.

Irradiation

Wien's law for the maximum emission is at a wavelength $\lambda_{\text{max}} = 2885000/T$ (nm).
Temperature

$$\begin{aligned}
 T_{vc} &= 0.0552 \cdot T_a^{3/2}, \\
 T_{vc} &= 0.0552 \cdot (T_a + 273.16)^{3/2} - 273.16.
 \end{aligned} \tag{2.21}$$

The total radiative flow radiated between two gray surfaces facing for the low Stefan-Boltzman

$$\phi_{\text{rad},12} = \varepsilon_{12} \cdot \mathfrak{I}_{12} \cdot \sigma \cdot (T_1^4 - T_2^4) \quad (\text{W/m}^2), \tag{2.22}$$

where $\sigma = 5.6699 \times 10^{-8}$ (W/m² K⁴), ε_{12} = emissivity between the surface areas 1 and 2; assuming opaque bodies facing a series of reflections between two surfaces leads to

$$\varepsilon_{12} = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1}. \quad (2.23)$$

If you think you do not have reflection: $\varepsilon_{12} = \varepsilon_1 \cdot \varepsilon_2$. $\mathcal{J}_{12}$, the view factor is the fraction of the total radiation emitted by a surface that affects surface 2 in many cases, the greenhouse is next to 1.

For a surface issues, one will have

$$\varepsilon + \tau + \zeta = 1, \quad (2.24)$$

where ε = emissivity in the infrared, τ = transmissivity in the infrared, and ρ = reflectivity in the infrared.

Obviously, for opaque bodies, $\tau = 0$, and therefore, $\varepsilon + \zeta = 1$.

Considering a flat wall, thickness s (m), of the surface S (m²), which defines the interior of a generic building, indoor and outdoor air temperatures are required T_i and T_e different but constant over time (steady) (see Figure 1).

The flow of heat Q_t (W) takes the following path [32]:

(1) adduction

$$Q_t = \alpha_i S (T_i - T_1), \quad (2.25)$$

where α_i = factor adduction internal [W m⁻² K⁻¹],

(2) conductivity

$$Q_t = \lambda \frac{S}{s} (T_1 - T_2), \quad (2.26)$$

where: λ = Thermal conductivity of wall (W/m K), S = surface wall (m²), and s = thick (m),

(3) adduction

$$Q_t = \alpha_e S (T_2 - T_e), \quad (2.27)$$

where α_e = factor adduction external (W/m² K).

Steady thermal power transmitted in the three steps must be constant; the thermal flows Q_t of the three terms must be equal, and therefore, solving the above equations according to differences in temperature, one has

$$\begin{aligned}(T_i - T_1) &= Q_t \frac{1}{\alpha_i S}, \\(T_1 - T_2) &= Q_t \frac{s}{\lambda S}, \\(T_2 - T_e) &= Q_t \frac{1}{\alpha_e S},\end{aligned}\tag{2.28}$$

$$(T_i - T_e) = \frac{Q_t}{S} \left(\frac{1}{\alpha_i} + \frac{s}{\lambda} + \frac{1}{\alpha_e} \right),$$

where R = thermal resistance ($\text{m}^2 \text{K/W}$),

$$\begin{aligned}R &= \left(\frac{1}{\alpha_i} + \frac{s}{\lambda} + \frac{1}{\alpha_e} \right), \\(T_i - T_e) &= \frac{Q_t}{S} R, \\Q_t &= \frac{S}{R} (T_i - T_e),\end{aligned}\tag{2.29}$$

where $K = 1/R$ global factor transmission ($\text{W/m}^2 \text{K}$),

$$K = \frac{1}{(1/\alpha_i + s/\lambda + 1/\alpha_e)}.\tag{2.30}$$

The flow heat through a flat, steady wall

$$\begin{aligned}Q_t &= KS(T_i - T_e), \\Q_t &= KS\Delta T.\end{aligned}\tag{2.31}$$

The total energy lost (kJ h^{-1}) in transmission result in an hour

$$\begin{aligned}E_{\text{tr}} &= 3,6 \cdot \sum_1^n Q_{t_i}, \\E_{\text{tr}} &= 3,6 \cdot \sum_1^n S_i k_i (T_i - T_e).\end{aligned}\tag{2.32}$$

2.2.3. Heat of Condensation

To calculate the heat of condensation [33]

$$Q = g \cdot \lambda \cdot A \quad [\text{W}], \quad (2.33)$$

where g = grams of water condensed [$\text{g s}^{-1} \text{m}^{-2}$], λ = latent heat of vaporization [J g^{-1}], and A = surface cover [m^2].

The report on the convective exchanges between the air inside and the inside surface of the cover

$$Q = Q' + Q'' = \alpha_{\text{int}} \cdot A \cdot (T_{\text{aria int}} - T_{\text{parete int}}) + g \cdot \lambda \cdot A. \quad (2.34)$$

Rearranging the terms

$$\begin{aligned} Q \cdot \frac{1}{\alpha_{\text{int}}} - \frac{g \cdot \lambda \cdot A}{\alpha_{\text{int}}} &= A \cdot (T_{\text{aria int}} - T_{\text{parete int}}), \\ Q \cdot \frac{1}{K_t} &= A \cdot (T_{\text{parete int}} - T_{\text{parete est}}), \\ Q \cdot \frac{1}{\alpha_{\text{est}}} &= A \cdot (T_{\text{parete est}} - T_{\text{aria est}}), \end{aligned} \quad (2.35)$$

$$Q \cdot \left(\frac{1}{\alpha_{\text{int}}} + \frac{1}{K_t} + \frac{1}{\alpha_{\text{est}}} \right) - \frac{g \cdot \lambda \cdot A}{\alpha_{\text{int}}} = A \cdot (T_{\text{aria int}} - T_{\text{aria est}}),$$

with: $K = 1/(1/\alpha_{\text{int}} + 1/K_t + 1/\alpha_{\text{est}})$, we have

$$Q = K \cdot A \cdot (T_{\text{aria int}} - T_{\text{aria est}}) + \frac{K}{\alpha_{\text{int}}} \cdot g \cdot \lambda \cdot A. \quad (2.36)$$

2.2.4. Heat Ventilation

The functions of ventilation in a greenhouse are:

- (i) replacement of oxygen and CO_2 ,
- (ii) temperature regulation,
- (iii) humidity control in greenhouses.

The requirements to be met are as follows [34]:

- (i) there must be direct air currents on plants, although there must be good air near the plants,
- (ii) incoming air flow should not move immediately on plants,

Figure 1

- (iii) ventilation equipment should be modular and should be able to seal to hold heat loss,
- (iv) fans must be water-resistant,
- (v) the construction of the fans should allow operation in all weather conditions,
- (vi) the size of the fans must be sufficiently large.

The heat dispersed by ventilation is

$$E_v = V(H_i - H_e). \quad (2.37)$$

3. The Basic Model of Simulation Greenhouse

The simulation of climate parameters of the greenhouse is made with a model that calculates the thermal exchanges in nonstationary [35]. Depending on the parameter, one can highlight energy waste and improve the design of the greenhouse. The created model can be applied in any type of greenhouse changing design parameters in the TYPE 56.

3.1. Model Creation

The greenhouse considered is a prefabricated construction in steel used as a greenhouse for growing flowers and plants. It is covered with glass cover, horizontal beam pattern, and small flat foot north and south.

The approach of the model was carried out by using the program TRNSYS Simulation Studio. It was done starting with the path leading to the construction of a multizone building, which is divided into multiple steps, where the user enters the data on building and its location in space [36]. The data required by the software at this stage will be used for the automatic construction of the project and its connections between the components will be divided into nine steps in which one inserts the following:

- (i) the indication of the areas, the number, and the arrangement with each other identify the adjacent walls and their arrangement with respect to north,
- (ii) the name of each area and plant size, height of walls and eaves, and length and width of each zone. Software automatically calculates the volume of each zone,
- (iii) the percentage of windows on each exterior wall of the building. This indicates the ratio of surface area between the windows and the wall multiplied by one hundred, in addition to adding the rotation angle of the building than the north and the source of meteorological data that will be used in the simulation. This is indeed a link with the Type 109 (Weather Data Processor), and in this case study, the meteorological station of Ancona-Falconara (Airport) was selected.

The meteorological station of Ancona is the weather station of reference for the Air Force Meteorological Service and the World Meteorological Organization concerning the city of Ancona and its coastline. The distance as the crow flies from this weather station and location of the emissions test is about 25 km. With the various components of TRNSYS have been created on the basis of meteorological data coordinates of the site and its features, the availability of measured values within a small radius improves performance [37].

The seepage goes through building walls, values, and modes of natural and mechanical ventilation for the building. These reported values in terms of number of air changes per hour (1/h). The inclusion of these data can still be changed later in the settings of each area. Natural ventilation was set by a temperature sensor that, for given temperature, regulates the process of opening the window (opens and closes at 25°C to 15°C).

The values of heating or cooling include the following. One must put the specific thermal power (W/m^2) component and radiant temperature values for which the process begins and ends. In this case, there has been nothing since the emissions in question does not have such means. These values apply to the whole building and can be changed later in the description of each area [38].

Other values of thermal power for people, accessories, and lighting include the following. The lighting can be managed according to the brightness outside. Even in this case, it was not included at all, because it was not present in the greenhouse test. These values apply to the whole building and can be changed later in the description of each area.

The values of external shading projections for each exterior wall oriented include the following. These projections are divided between the top or side windows. The greenhouse has no such means of external shading.

The values of shading means for shading furniture inside or outside each exterior wall oriented include the following. Their operation is controlled according to the brightness outside. They can also be inserted values for maximum shading external and internal components.

In the window on the last step, we must not put anything but only to confirm data. At this point, the software creates a description of the building in a data file (*.blinds), opens TRNBuild and translates the data file formats needed for the simulation (.bld and .Trn), and finally create a simulation project automatically saving a file (.TMF) and opens in the Simulation Studio. At this point, it is already possible to test the project by running a simulation.

This procedure simplifies the model construction, since the opening of the Simulation Study of climatic data processor [39] (Type 109) is already connected to the components of solar radiation, air temperature, psychrometric data processor, and these in turn are related to the greenhouse. It is also established a conversion system orientation of the greenhouse

(Turn) which is connected to the processor of climatic data for the management of the greenhouse, and they are designed to control artificial lighting and natural ventilation related to each pavilion. There are no regulators of heating and cooling because they were not expected during project creation.

After creating the preliminary draft, changed data is placed within the individual components of the Simulation Study that those inside the TRNBuild were opening directly from the icon building. This work is necessary because the description of the walls and windows of the building is set automatically to a dwelling and not for a greenhouse; in addition, there will be no roof, let alone the calculations of the radiation incident on the roof itself.

To change the initial project, it was started by a description of the greenhouse through the opening of TRNBuild. Through dialog boxes, it was done by adding the orientation of the water and the software automatically included the presence of cover. So, we changed the descriptions of each area. We changed the volume of each zone to also consider the space under the foot and have changed the properties of building walls to fit with those of the greenhouse test [40].

It should be noted that despite the walls and ground that the greenhouse comprises, besides the metal structure, through the windows, they were not included in the description of the external walls but in the windows. This is because the lighting calculations are performed inside the greenhouse through the indices of transmission of solar radiation of their windows, while the walls are not done as thoroughly described in the paragraphs relating to optical properties and thermal windows. Setting windows as external walls would, therefore, lead light inside the greenhouse.

That said, in describing the external walls and ground are included the values of the metal structure. To this end, we created a new type of material (galvanized steel), and its geometric and thermodynamic data are reported by the manufacturer.

Even the windows have created a new type that reflects that of a single-glass greenhouse. The type and properties of glass were in the library of the program, but it was necessary to correct the size and relationship frame/window (the area of the casing split window area) [41].

Regarding the “wall” soil, values of the different layers were included that make up the ground as instructed by the owners of the greenhouse working to run the nursery.

The “wall” soil can also be treated as wall bound (boundary) or linked to soil temperature simulator creating an input to the Type 56.

For each wall must be shown the value of GEOSURF, which may be a fixed value (automatically set as the preliminary description) or an input or a tab. Given the extreme importance that the radiation in this study, it was decided to link data on areas of direct radiation generated by the Type 109 as input to each wall (Figure 2) where weather date: weather generator, Psychrometrics: processor psychrometric, Sky Temp: CPU temperature sky, Radiation: radiation converter, Greenhouse: Greenhouse (Type 56), Nat. Vent. 1 and 2: controllers of ventilation, Turn: unit converters, and Charts: Online Plotter.

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For a correct simulation of humidity inside the greenhouse, one must consider the input of water due to transpiration of plants. Since the calculation of the transpiration of plants is extremely complex, models should be entrusted to a specific type to run which is

Figure 2: Graphic display of the project.

not one of those available in the program. To simplify the introduction of these constants of transpired water found in the bibliography, the constancy of these values depends on the type of nursery practice and short cycle of the plants.

After finishing the detailed description of the greenhouse, we saved the changes and updated the list of variables (inputs) of the Type 56. This helps to find new items to be served, on the data of solar radiation incident on the slopes of the greenhouse [42].

These data were to be created, however, the Type 109 by inserting two new surfaces on which to assess the components of the radiation, further defining their azimuth and inclination (which is that of water). So, by this component, outputs are automatically generated to ground, which must be connected to the component "Radiation" and then to the greenhouse. Even through the component "Radiation" was necessary to arrange the transfer of this information by creating input and output.

3.2. General Mathematical Description of the Thermal Model

The general case, which does not include the simplified model of the heating and cooling equipment, is presented first. If separate equipment components are used, they can be coupled to the zones as either internal convective gains or ventilation gains [43]. Following this, the simplified method of providing heating and cooling equipment within the TYPE 56 component is described.

Another section will cover the use of a simulation timestep that is not equal to the time base on which the wall transfer function relationships are based. Finally, descriptions of the optical and thermal window model, the way in which solar and internal radiation are distributed within each zone; the moisture balance calculations and the integrated model for thermo-active walls are given (see Figure 3).

Figure 3: Interzonal air change, cross ventilation, and ventilation circle.

3.2.1. Thermal Zone

The building model in TYPE 56 is a nongeometrical balance model with one air node per zone, representing the thermal capacity of the zone air volume and capacities which are closely connected with the air node (furniture, e.g.) [44]. Thus, the node capacity is a separate input in addition to the zone volume.

Convective Heat Flux to the Air Node

$$Q_i = Q_{\text{surf},i} + Q_{\text{inf},i} + Q_{\text{vent}} + Q_{g,c,i} + Q_{\text{cplg},i}, \quad (3.1)$$

where $Q_{\text{surf},i}$ = convective heat flow from all inside surfaces, $Q_{\text{surf},i} = U_{w,i} * A_{w,i} (T_{\text{wall},i} - T_{\text{air}})$, $Q_{\text{inf},i}$ = infiltration gains (air flow from outside only), $Q_{\text{inf},i} = V * \rho * c_p (T_{\text{esterna}} - T_{\text{air}})$, Q_{vent} = ventilation gains (air flow from a user defined, source like an HVAC system), $Q_{\text{vent}} = V * \rho * c_p (T_{\text{ventilation},i} - T_{\text{air}})$, $Q_{g,c,i}$ = internal convective gains (by people, equipment, illumination, radiators, etc.), $Q_{g,c,i} = [\text{kJ/h}]$, $Q_{\text{cplg},i}$ = gains due to (connective) air flow from zone i or boundary condition, and $Q_{\text{cplg},i} = V * \rho * c_p (T_{\text{zone},i} - T_{\text{air}})$.

Coupling

The coupling statement allows the definition an air mass flow a zone receives from another zone, considered as a heat flow from or to the air node. The statement does not automatically define the air flow back to the adjacent zone as would occur in an interzonal air exchange [11]. To consider this return flow, the corresponding coupling must be defined in the adjacent zone to receive the same air flow in return. The reason for this convention is to allow the user to describe cross ventilation or a ventilation circle within 3 or more zones (thermosyphon through a 2-story winter-garden, e.g.).

Figure 4: Radiative energy flows considering one wall with its surface temperature node.

Note: There is no air balance check in TYPE 56. The user can empty or overload a zone by couplings. We are sure that the specified air flows into a zone by coupling, ventilation, and infiltration are physically meaningful (see Figure 5).

3.2.2. Radiative Heat Flows (Only) to the Walls and Windows

$$Q_{r,wi} = Q_{r,wi} + Q_{g,r,i,wi} + Q_{sol,wi} + Q_{long,wi} + Q_{wall-gain}, \quad (3.2)$$

where $Q_{r,wi}$ = radiative gains for the wall surface temperature node [kJ/h], $Q_{g,r,i,wi}$ = radiative zone internal gains received by wall [kJ/h], $Q_{sol,wi}$ = solar gains through zone windows received by wall [kJ/h], $Q_{long,wi}$ = long-wave radiation exchange between this wall and all other walls and windows ($\varepsilon_i = 1$) [kJ/h], and $Q_{wall-gain}$ = surface or window wall the to flow heat specified user [kJ/h].

In the following subsections, [9], the expressions used for the calculation of these energy quantities are given. The procedures for calculating floating temperatures and energy demands follow.

3.2.3. Integration of Walls and Windows

Figure 5 shows the heat fluxes and temperatures [10] that characterize the thermal behavior of any wall or window. The nomenclature used in Figure 4 is defined as follows: $S_{s,i}$ = radiation heat flux absorbed at the inside surface (solar and radiative gains), $S_{s,o}$ = radiation heat flux absorbed at the outside surface (solar gains), $q_{r,s,i}$ = net radiative heat transfer with all other surfaces within the zone, $q_{r,s,o}$ = net radiative heat transfer with all surfaces in view of the outside surface, $q_{w,g,i}$ = user defined heat flux to the wall or window surface, $q_{s,i}$ = conduction heat flux from the wall at the inside surface, $q_{s,o}$ = conduction heat flux into the wall at the outside surface, $q_{c,s,i}$ = convection heat flux from the inside surface to the zone air, $q_{c,s,o}$ = convection heat flux to the outside surface from the boundary/ambient, $T_{s,i}$ = inside surface temperature, $T_{s,o}$ = outside surface temperature, T_i = temperature of zone i (air node), and $T_{a,s}$ = temperature of ambient air at the outer boundary of surface.

Figure 5: Surface heat fluxes and temperatures.

Table 2: Example wall for calculate the transfer function coefficient.

Material data	Thickness [m]	Conductivity [kJ/h m K]	Capacity [kJ/kg K]	Density [kg/m ³]
Concrete	0.025	7.56	1.0	2400
Mineral wool	0.08	0.144	1.0	40
Gypsum	0.02	2.52	1.0	1400

The walls are modelled according to the transfer function relationships of Mitalas and Arseneault defined from surface to surface. For any wall, the heat conduction at the surfaces are

$$\begin{aligned}
 \dot{q}_{s,i} &= \sum_{k=0}^{n_{b_s}} b_s^k T_{s,o}^k = \sum_{k=0}^{n_{c_s}} c_s^k T_{s,i}^k = \sum_{k=1}^{n_{d_s}} d_s^k \dot{q}_{s,i}^k, \\
 \dot{q}_{s,o} &= \sum_{k=0}^{n_{a_s}} a_s^k T_{s,o}^k = \sum_{k=0}^{n_{b_s}} b_s^k T_{s,i}^k = \sum_{k=1}^{n_{d_s}} d_s^k \dot{q}_{s,o}^k.
 \end{aligned} \tag{3.3}$$

3.2.4. Transfer Function Method by Mitalas

The method of the transfer function or response factors can be described as the method to tell the “thermal history” of the wall [7]. The wall is considered as a black box. The number of timesteps (k) related to the time base (defined by the user) shows whether the wall is a heavy wall with a high thermal mass (k_{20}) or if only a few timesteps have to be considered to describe the thermal behavior of this wall. If the time base of the considered wall is higher than the time constant, the calculation of the Transfer-function matrix coefficients is stopped. Therefore, such a “thin” wall can be replaced by a resistance definition neglecting the thermal mass. As an example, Figure 6 shows the different material layers of a wall.

The wall example consists of three layers with concrete, mineral wool, and gypsum from outside to inside (see Tables 2 and 3).

Figure 6: Real wall and black box model of the wall.

Table 3: Thermal conductance, $U = 1.76429 \text{ KJ/h m}^2 \text{ K}$; $k\text{-Wert} = 0.45239 \text{ W/m}^2 \text{ K}$.

K	Transfer function coefficients			
	A	B	C	D
0	$3.0402072E + 01$	$8.6597596E - 01$	$6.2473097E + 01$	$1.0000000E + 00$
1	$-2.8791436E + 01$	$8.7958309E - 01$	$-6.1044043E + 01$	$-5.5725114E - 03$
2	$1.4382785E - 01$	$8.9032318E - 03$	$3.2541274E - 01$	$1.0083948E - 07$
3	$-1.0589132E - 06$	$4.0042651E - 07$	$-4.7183532E - 06$	
SUM	$1.7544627E + 00$	$1.7544627E + 00$	$1.7544627E + 00$	$9.9442759E - 01$

Using the transfer function method, the TRNBUILD program calculates the transfer function coefficients, listed below for the example wall.

For the test wall, the coefficient table looks like that in Table 3. In addition to the transfer function coefficients, the listing contains a calculation of the heat conduction value U of the wall construction and the total heat transfer coefficient k considering a constant combined (convective + radiative) heat transfer ($_i, _o$) for the inside and outside surface.

3.2.5. The Long-Wave Radiation

The long-wave radiation exchange between the surfaces within the zone and the convective heat flux from the inside surfaces to the zone air are approximated using the star network given by Seem [3] and represented in Figure 7. This method uses an artificial temperature node (T_{star}) to consider the parallel energy flow from a wall surface by convection to the air node and by radiation to other wall and window elements. Comparisons to the detailed building model JOULOTTA from the University of Lund, Sweden, done by S. Holst, ZAE Munich, show a good agreement for the surface temperatures. A single node model using a combined convective and radiative heat transfer coefficient shows much higher differences (IEA Task 13 report)

$$R_{\text{STAR},i} = f(\alpha_i, A_{\text{Surf},i}) = \frac{1}{Q_{\text{surf},i}} (T_{\text{Star}} - T_i). \quad (3.4)$$

Figure 7: Star network for a zone with three surfaces.

Methods to calculate the resistances $R_{equiv,i}$ and $R_{star,i}$ can be found in reference. Area ratios are used in these calculations to find the absorption factors between all surfaces. The star temperature can be used to calculate a net radiative and convective heat flux from the inside wall surface

$$\dot{q}_{comb,s,i} = \dot{q}_{c,s,i} + \dot{q}_{r,s,i}, \quad (3.5)$$

then,

$$\dot{q}_{comb,s,i} = \frac{1}{R_{equiv,i} A_{s,i}} (T_{s,i} - T_{star}), \quad (3.6)$$

where $q_{comb,s,i}$ = combined convective and radiative heat flux and $A_{s,i}$ = inside surface area.

For external surfaces the long-wave radiation exchange at the outside surface is considered explicitly using a fictive sky temperature, T_{sky} , which is an input to the TYPE 56 model and a view factor to the sky, f_{sky} , for each external surface. The total heat transfer $q_{comb,s,i}$ is given as the sum of convective and radiative heat transfer

$$\dot{q}_{comb,s,o} = \dot{q}_{c,s,o} + \dot{q}_{r,s,o}, \quad (3.7)$$

with,

$$\begin{aligned}\dot{q}_{c,s,o} &= h_{\text{conv},s,o} \cdot (T_{a,s} - T_{s,o}), \\ \dot{q}_{r,s,o} &= \sigma \cdot \varepsilon_{s,o} \cdot (T_{s,o}^4 - T_{f_{\text{sky}}}^4), \\ T_{f_{\text{sky}}} &= (1 - f_{\text{sky}}) \cdot T_{a,s} + f_{\text{sky}} \cdot T_{\text{sky}},\end{aligned}\tag{3.8}$$

where $q_{\text{comb},s,o}$ = combined convective and radiative heat flux to the surface, $q_{c,s,o}$ = convective heat flux to the surface, $q_{r,s,o}$ = radiative heat flux to the surface, $h_{\text{conv},s,o}$ = convective heat transfer coefficient at the outside surface, f_{sky} = fraction of the sky seen by the outside surface (for a vertical wall with no buildings nearby, a reasonable value for f_{sky} is 0.5. If there are buildings in front of the wall obstructing the view of the sky, the value for f_{sky} would be lower than 0.5. For a horizontal roof with only the sky in view, f_{sky} would be 1.0), T_{sky} = fictive sky temperature used for long-wave radiation exchange, $\varepsilon_{s,o}$ = long-wave emissivity of outside surface ($\varepsilon = 0.9$ for walls, value read from window library for windows), and σ = Stephan-Boltzman constant.

Energy balances at the surfaces give

$$\begin{aligned}\dot{q}_{s,i} &= \dot{q}_{\text{comb},s,i} + S_{s,i} + \text{Wall-gain}, \\ \dot{q}_{s,o} &= \dot{q}_{\text{comb},s,o} + S_{s,o}.\end{aligned}\tag{3.9}$$

For internal surfaces, $S_{s,i}$ can include both solar radiative and long-wave radiation generated from internal objects such as people or furniture.

Wall-gain is a user-defined energy flow to the inside wall or window surfaces. It can describe solar gains changing during the day due to different sun positions or might be used as a simple way to model a floor heating or a ceiling cooling system. For external surfaces, $S_{s,o}$ consists of solar radiation only.

3.2.6. Infiltration, Ventilation, and Convective Coupling

Infiltration and ventilation rates are given in terms of air changes per hour for each zone. The mass flow rate is the product of the zone air volume, air density, and air change rate. Infiltration occurs always from outdoor conditions, while ventilation occurs from a specified (possibly variable) temperature. Equal amounts of air are assumed to leave the zone at the zone [45] temperature. The energy gains to any zone i due to infiltration and ventilation are

$$\begin{aligned}\dot{Q}_{\text{inf},i} &= \dot{m}_{\text{inf},i} C_p (T_a - T_i), \\ \dot{Q}_{v,i} &= \sum_k^{\text{n vent}} \dot{m}_{v,k,i} C_p (T_{v,k} - T_i),\end{aligned}\tag{3.10}$$

where $\dot{m}_{\text{inf},i}$ = mass flow rate of infiltration air, $\dot{m}_{v,k,i}$ = mass flow rate of ventilation air of ventilation type k , C_p = specific heat of the air, $T_{v,k}$ = temperature of ventilation air of ventilation type k , and T_a = ambient air temperature.

For each wall or window separating zones of floating temperature or each wall having a known boundary condition, it is possible to specify a convective coupling. This coupling is the mass flow rate that enters the zone across the surface. An equal quantity of air is assumed to leave the zone at the zone temperature. The energy gain due to the convective coupling is the sum of all such gains for all walls or windows in the zone

$$\dot{Q}_{\text{cplg},i} = \sum_{\text{adj zones}} \sum_{\text{surfaces}} \sum_{\text{sitto } j} \dot{m}_{\text{cplg},s} C_p (T_j - T_i) + \cdots + \sum_{\text{Known bound}} \dot{m}_{\text{cplg},s} C_p (T_{b,s} - T_i), \quad (3.11)$$

where $\dot{m}_{\text{cplg},s}$ = the mass flow rate of air *entering* zone i across walls or windows.

3.2.7. Distribution of Solar Radiation

The incoming (primary) direct solar radiation is distributed according to the distribution coefficients (GEOSURF) defined in the building description. These values are distribution factors related to the total direct solar radiation entering the zone and not related to a surface area. The sum of GEOSURF values given for all inside surfaces of a zone should sum up to 1 at all times. The fraction of incoming direct solar that is absorbed by any surface i is given by the product of solar absorptance α_s value times the GEOSURF value given for this surface s . If the GEOSURF values for all surfaces of a zone are set to zero, all direct solar radiation entering this zone is treated as diffuse radiation (like in TRNSYS 14.2) and distributed with the absorptance weighted area ratios described below. Note: as for the distribution of primary direct solar radiation there is no dependence on the surface area, it is possible to concentrate all direct solar to a small surface by giving it a high value of GEOSURF. This would result in very high surface temperatures and possible.

Instabilities in Solving the Energy Balance Equations of TYPE 56

After passing the second internal window, all solar radiation is treated as diffuse radiation. To pass direct solar radiation over several zones like in a atria from the top zone to the middle zone to the bottom zone a fictive window between top and bottom zone might be used. The incoming diffuse solar radiation and reflected primary direct solar radiation is distributed according to absorptance-weighted area ratios. The fraction of diffuse solar that is absorbed by any surface s is

$$f_{\text{dif},s,s} = \frac{\alpha_s A_s}{\sum_{\text{surfaces}} (1 - \rho_{d,s}) A_s}, \quad (3.12)$$

where α_s = the solar absorptance of the surface (defined in the building description), and $\rho_{d,s}$ = the reflectance for diffuse solar of the surface for wall surfaces where $\tau_s = 0$, $\rho_{d,s} = (1 - \alpha_s)$. For windows, the transmission losses are considered by $\tau_s = (1 - \alpha_s - \rho_{d,s})$, and $\rho_{d,s}$ = reflectance for diffuse solar from inside.

3.2.8. Distribution of Long-Wave Radiation

All surfaces are assumed to be black for long-wave radiative exchange and radiative internal gains. These gains are distributed according to area ratios. The fraction of the internal radiative gains for any zone that is adsorbed by a surface s is

$$f_{l,s} = \frac{A_s}{\sum_{\text{surfaces}} A_s}. \quad (3.13)$$

3.2.9. Moisture Balance

In parallel with the sensible energy balance calculation, TYPE 56 calculates a moisture balance considering free floating humidity ratios or humidification/dehumidification to a certain setpoint. In this case, TYPE 56 calculates the latent load. There are two models for the calculation of the moisture balance available in TYPE 56. The first model considers sorption effects with an enlarged moisture capacity of the zone air the second, more sophisticated, model offers a surface and a deep moisture buffer in the walls of the zone.

3.2.10. Effective Capacitance Humidity Model

In the first model, the buffer effect of adsorptive and desorptive materials, soil areas, or plants is considered by an effective moisture capacitance which is defined as the product of the zone air mass and a moisture capacitance ratio [4]

$$M_{\text{eff},i} = \text{Ratio} * M_{\text{air},i}, \quad (3.14)$$

where $M_{\text{eff},i}$ = effective moisture capacitance of the zone, $M_{\text{air},i}$ = the mass of air in the zone, Ratio = multiplication factor generally in the range of 1 to 10, and A moisture balance for any zone results in the following differential equation.

$$M_{\text{eff},i} \frac{d\omega_i}{dt} = \dot{m}_{\text{inf},i}(\omega_a - \omega_i) + \sum_k^{\text{n vent}} \dot{m}_{v,k,i}(\omega_{v,k,i} - \omega_i) + W_{g,i} + \sum_{\text{surfaces } i-j} \dot{m}_{\text{cp lg},s}(\omega_j - \omega_i), \quad (3.15)$$

where: ω_i = the humidity ratio of the zone, ω_a = the ambient humidity ratio, $\omega_{v,k,i}$ = the humidity ratio of the ventilation air from ventilation type k , $W_{g,i}$ = internal moisture gains, and ω_j = the humidity ratio of an adjacent zone j .

In order to simplify the solution of the simultaneous set of differential equations, the values of ω at the end of the previous timestep are used in the above expression. Subroutine DIFFEQ is then used to independently solve for the final and average values of the humidity ratio over each timestep for each zone. If the average humidity ratio of the zone falls below or rises above a setpoint for humidification or dehumidification, then latent energy is added

or removed to maintain the humidity ratio at the setpoint. It is assumed that the change in zone humidity ratio occurs instantly so that $\omega_i = \omega_i$. In this case,

$$Q_{\text{lat},i} = h_v \left[\dot{m}_{\text{inf},i}(\omega_a - \omega_{\text{req},i}) + \sum_k^{\text{n vent}} m_{v,k,i}(\omega_{v,k,i} - \omega_{\text{req},i}) + W_{g,i} + \sum_{\text{surfaces } i-j} m_{\text{cplg},s}(\omega_{f,i,M} - \omega_{i,s,M}) - \frac{M_{\text{eff},s}(\omega_{\text{req},i} - \omega_{i,M})}{\Delta t} \right], \quad (3.16)$$

where $Q_{\text{lat},i}$ = latent energy removed (+dehumidification, –humidification), h_v = the heat of vaporization of water, and $\omega_{\text{req},i}$ = the setpoint for humidification or dehumidification

Between the two setpoints, the humidity ratio is free floating.

3.3. Simulation Result

With the model designed, it is able to simulate the parameters of the greenhouse climate, check the energy required for conditioning the glass or the ideal conditions for the cultivation of a species. Thus, in the planning stages, you can optimize the construction parameters of the greenhouse according to the following:

- (i) climatic growing demands identified,
- (ii) the climatic parameters of the geographical [46].

With simulation one can find the best building materials for the needs of crops. In particular, the following were simulated:

- (i) solar radiation inside a function of incident radiation,
- (ii) internal temperature in the outside temperature,
- (iii) relative humidity.

3.3.1. Simulation of Annual Solar Radiation Inside the Greenhouse (W/m^2)

The solar radiation arrives in the greenhouse and affects the inside temperature.

In particular, the characteristics constructive of the greenhouse is 97% of the radiation incident reaches the ground and increases the internal temperature (Figure 8).

In Figure 9, we have compared the solar radiation inside with the incident one [47].

Checking on the low resistance of the solar radiation structure, which results to be an advantage during the winter months, with the only problem of a high energetic consumption for the cooling system.

During the cold months, the internal radiation is almost equal to the outside, while in the summer transmission of solar radiation falls on the most important reflection of the glass. This is due to the increased presence of direct radiation and different angles of incidence.

3.3.2. Simulation of Annual Temperature

Blue is outdoor temperature; indoor temperature is red (see Figure 10). During the winter months, the temperature is almost identical to the external light and low thermal capacity of

Figure 8: Simulation of annual solar radiation inside the greenhouse (W/m^2).

Figure 9: Simulation of annual solar radiation inside the greenhouse (W/m^2) in blue and external red.

the structure (infiltration losses of 1/h). During the warm months, open windows operated with a controller on/of (Type 2) to open windows when the temperature exceeds 30 degrees and provides an air supply of 20/h.

3.3.3. Simulation of Annual Relative Humidity (%)

In red and blue indoor humidity and external, the image is not very representative in the sense that the evapotranspiration is considered constant throughout the year and added to its average value, which is never verifiable as it varies from hour to hour and from day to night, depending the size of the leaves of plants (see Figures 11 and 12).

It is therefore more appropriate to show the graph of a typical day summer crop of tomatoes, with values of daily evapotranspiration inserted into a card.

Figure 10: Simulation of annual temperature.

Figure 11: Simulation of annual relative humidity (%).

During the month of June, we have compared the value of internal and external humidity, with a result of superior humidity inside than outside, without considering the evapotranspiration of the plants.

This parameter is important for the plant growth and requires a constant control.

4. Conclusions

TRNSYS software has demonstrated an extreme flexibility to allow development of the project emissions. The construction of the model has been simplified by the procedures explained in a comprehensive manner in the various manuals provided with the software without showing any particular difficulties in communications between the constituent subprograms.

Figure 12: Simulation of relative humidity (%) inside (red) and outside (blue) emissions in the hottest day of the year (July 27).

As for the light component of the simulations, the solution found to allow the passage of long-wave radiation through the windows of the greenhouse modeled as “windows” has perhaps shown a factor critical TRNBuild, or if we do not have the model for reporting light energy to the walls of buildings, this did not affect in any way the results. Moreover, this solution has improved the simulation of moisture for the cold bridge effect. From this model, it might be interesting to continue to work on projects for energy systems applied to agriculture, being able to predict the indoor climatic conditions, and from this starting to figure out which crops are actually achievable [6].

In addition, this program offers many opportunities to improve systems made: insertion of cooling and heating, dehumidification, the total consumption of electricity and machinery for the exercise of individual farming, the heat emitted the various electrical components inside the greenhouse, and everything else necessary to simulate the best situations in the various case studies. In order to build easily new components (type) on variables purely “agricultural” as the evaporator plant transpiration of water from soil.

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