F.lo.r.ener. a Model Focuses on Energy Management for Greenhouses

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Abstract
The reduction of energy consumption is among the main goals of modern cultivation technique under greenhouse conditions. Most of the protective structures used in the European Union are aged of more than 15 years and do not always conform to current standards of low energy consumption. In most cases, the cost of investment to rebuild greenhouse plant is much more expensive for possible interventions to save energy. In many cases the old greenhouses have a high rate of air infiltration and large dispersions of heat mainly from the roof and the ventilation system. In many cases heat shields are not used and ventilation is poorly managed. To evaluate alternatives in case of new structures or to implement old structures, a decision support system (DSS) was developed to help the users in taking decisions on different possibilities both concerning the structures or the management regime. Expected results includes strategies on general maintenance to reduce energy consumption and/or to increase crop yield or energy efficiency. The software analyzes the main choices the user can take on construction, cover material, inside climate, energy sources, location. The calculations consider a stationary condition, thus the inertia is not considered. The program aims to quantify the energy demand and the relevant costs in structures defined by the user. After the elaboration - based on flowcharts - the model gives outputs as graphs with external temperature, evaporation rate, ventilation, conduction, re-irradiation, minimum temperature required. Diffuse radiation, power required, and set temperature are also showed.

Keywords: protected cultivation, energy saving, decision support tool, economic analysis.

Introduction

Reducing energy consumption is, at present, one of the major goals of technical design and implementation of greenhouses. Maintaining low energy consumption for the production of ornamental plants is necessary to have a sustainable cost of production taking into account the distribution chain in the global market. Increasing the efficiency of these structures also contributes to the reduction of greenhouse gases emission imposed by the European rules. The reduction of energetic requirements has also to reduce convective and irradiative thermal losses of structures and covering materials (Abdel-Ghany et al., 2006), increasing the efficiency of conditioning systems (Arbel et al., 2003), introducing new management practices and adopting available renewable sources of energy. Most greenhouses at present used in the EU are not designed taking into account current standards of energy efficiency as they are aged of about 15-20 years being built when the cost of energy was not a strong limit. Not always it is necessary or convenient to demolish and rebuild old greenhouses; on the contrary, simplest operations such as reducing the air infiltration rate or changing the type of fuel could decrease the heat losses or obtain lowest environmental impacts with, at the same time, better economic performance. Practically, this means a range of interventions such as replacing the covering or the heating system, introducing aluminum heat shields, a special maintenance of the greenhouse or just adjusting the set points of the heating program. Given the range of possible and alternative solutions, the availability of a Decision Support System (DSS) can provide an aid in analyzing the existing situation, i.e. asking the users to enter the required data, and presenting different scenarios comparing energy requirements and costs. The software has to take into account the Italian extremely variable climatic conditions from North to South, the age and characteristics of most of the existing greenhouses and to provide information on new investments to be implemented in order to maintain the competitiveness of the production of ornamental plants. A dynamic computer simulation model to improve greenhouses energy efficiency was developed. The program aims to quantify the energy demand and the relevant cost in the structure indicated by the user. After the elaboration based on the flowchart, the model gives outputs on graphs.

Materials and methods

The software has been developed considering three subsequent phases: i) the creation of a virtual greenhouse for analysis; it requires the use of simple data such as size, shape materials, characteristics of the heating system, geographical location and species of plants cultivated over the year thus to determine what internal conditions must be maintained in the greenhouse (Figures 1 and 2); ii) the processing of the collected data by means of the calculation model (see the description below in the detail); iii) the displaying of the results in graphical form; it provides options on the indoor climatic conditions, the energy demand of the heating system and the relevant operating costs.

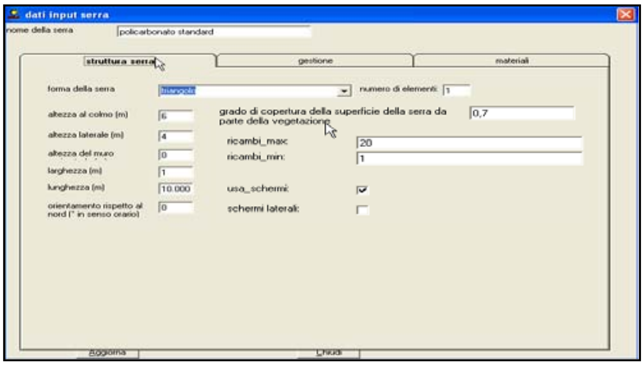
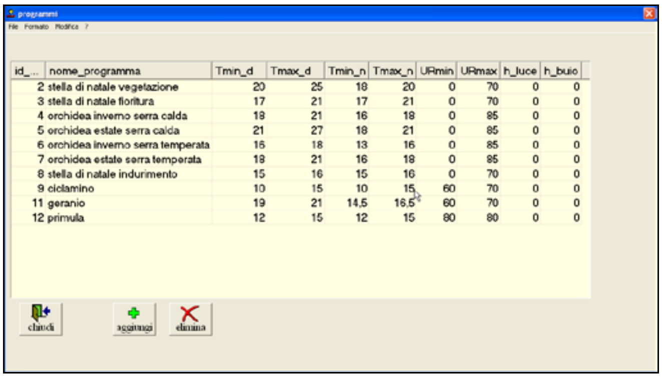


Fig. 1. An easy-to-fill mask indicates the layout of the structure to be analyzed.



id_...	nome_programma	Tmin_d	Tmax_d	Tmin_n	Tmax_n	URmin	URmax	h_luce	h_buio
2	stella di natale vegetazione	20	25	18	20	0	70	0	0
3	stella di natale fioritura	17	21	17	21	0	70	0	0
4	orchidea inverno serra calda	18	21	16	18	0	85	0	0
5	orchidea estate serra calda	21	27	18	21	0	85	0	0
6	orchidea inverno serra temperata	16	18	13	16	0	85	0	0
7	orchidea estate serra temperata	18	21	16	18	0	85	0	0
8	stella di natale indurimento	15	16	15	16	0	70	0	0
9	ciclamino	10	15	10	15	60	70	0	0
11	geranio	19	21	14,5	16,5	60	70	0	0
12	primula	12	15	12	15	80	80	0	0

Fig. 2. A directory with the planning of most popular crops with their relevant environment requirements.

The program updates each change and can save or delete settings; it allows the user to make subsequent alterations without having to re-create another virtual greenhouse.
The calculation considers a stationary condition, thus not taking into account the inertia. The model (Figures 3 and 4) is based on the follow algorithms:
Heat gained by radiation $qi = \tau \cdot I \cdot Af$ (W)
where τ: transmittance of the cover;
I: Global radiation ($W \cdot m^{-2}$);
Af: footprint of the greenhouse on the ground (m^2);
Heat released by heating qf = net power request to the heating (W);
Heat transmitted by conduction $qc = Ai \cdot U \cdot (Ti - Te)$ (W)
where U: coefficient of heat transmission ($W^{-2} \cdot m \cdot °C^{-1}$);
Ai: area of exposed glass (m^2);
Ti: internal temperature (°C);
Te: external temperature (°C);
Heat provided by the ventilation $qv = M \cdot cp \cdot (Ti - Te)$ (W)
where M: air flow rate at $kg \cdot s^{-1}$;
cp: specific heat of air equal to 1005 $J \cdot kg^{-1} \cdot °C^{-1}$;
M value is based on flow rate required to keep the inside humidity below the required maximum value. The flow-rate is obtained by the following equation: $M = Water \cdot (Ue - Ui)^{-1}$
where M is the air flow rate in $kg \cdot s^{-1}$;
Water is the amount of evaporated water in the time unit ($kg \cdot s^{-1}$)
Ue, Ui are respectively the external and internal absolute humidity.
Water derives from the latent heat calculation (ql).
Under conditions of low or no radiation (night), the evaporated water can be calculated as a proportion of water evaporated from a free surface.
In this case, you use the following report (empirical): $g = k \cdot Af \cdot (xs-x) \cdot F \cdot r/3.6$ ($H_2O\ g \cdot s^{-1}$) where k: $(25+19 \cdot v)$;
v: air velocity inside the greenhouse ($m \cdot s^{-1}$) default to 0.2 $m \cdot s^{-1}$
F: degree of coverage of the crop in the greenhouse (decimal value);
xs: water content of air inside (instead of as a set point);
x: water content of the internal temperature of saturation;
r: coefficient reduction from empirical evaporation potential to place 0.7;
Heat lost by radiation of the greenhouse $qt = \varepsilon s \cdot \tau t \cdot \sigma \cdot Af \cdot (TKi^4 - \varepsilon a \cdot TKe^4)$ (W)
where εs: Surface emissivity (default value 0.85);
τt: thermal transmittance of the material ;
σ: constant of Stefan-Boltzman ($5.67 \cdot 10^{-8}\ W \cdot m^{-2}$);
TKI: absolute internal temperature (°K);
Ea: the air apparent emissivity (a function of dew point);
TKE: absolute external temperature (°K);
Latent heat for evapo-transpiration (taking a share of radiation) $ql = E \cdot F \cdot qi$ (W)
where E: evapo-transpiration relationship between decimal and heat by radiation;
qi: heat gained by radiation (W);
Heat balance $qi + qf = qc + qt + qv + ql$.

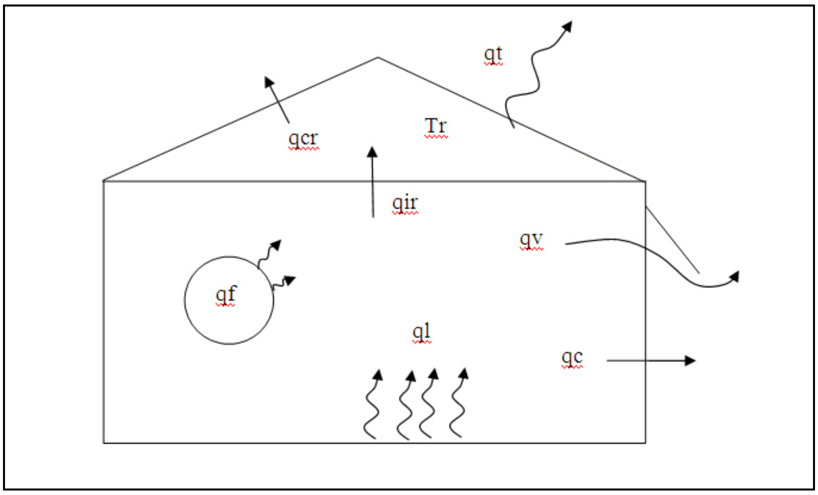


Fig. 3. Schematic outline of a greenhouse provided with heat shields.

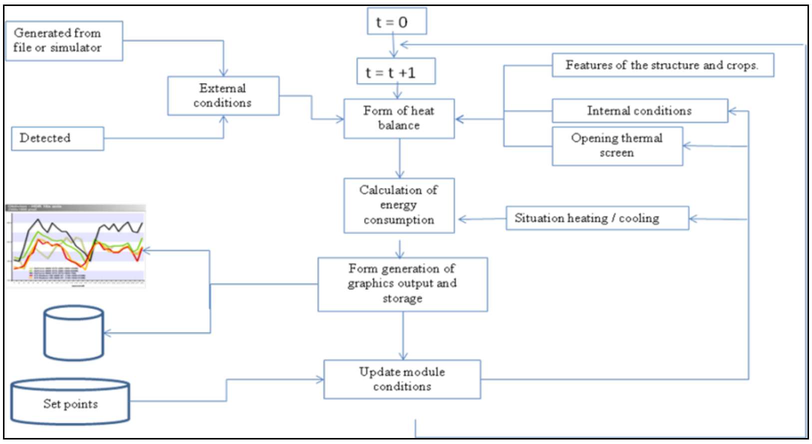


Fig. 4. Flowchart of the developed model.

If the model considers the presence of energy screens, the following two conditions have been considered: the global radiation is below 20-40 W · m^{-2} and the greenhouse requires heating. In these cases, the calculation is based on two steps: calculation of the temperature above screens (Tr) and calculation of heat requirement for maintaining the internal T value. Tr is based on the following concept: qir = qcr + qt where qir is the heat transmitted by conduction through the screen (W); qcr is the heat transmitted by conduction from the top outside (W); qt is the heat transmitted by radiation from the greenhouse (W). Once founded Tr by means of iterative calculation, the model indicates the following for the area below the screen: qf = qc + ql + qir + qv, where qc is the heat transmitted by conduction from the area under the screens to the outside (W).
The other terms are the same as those used in the calculation without screens. Therefore, ventilation is considered to be exclusively under the screens.

Results

An example of an elaborated graphic with outputs relative on external temperature, evaporation, ventilation, conduction, re-irradiation, minimum temperature required is provided in Fig. 5. Diffuse radiation, power required, and set temperature are showed in Figure 6. The data derives from calculation based on a specific greenhouse design which characteristics have been introduced in the software by the user. The software gives the possibility to vary the structure layout or the management strategy in order to put the user in condition to compare alternative solutions. One of the most important source of variability of the model derives from the year-to-year variability in weather conditions. In this case, the considered database on local climatic conditions was obtained by averaging, over ten years, the hourly values of the parameters taken into consideration such as air temperature and humidity and solar radiation.

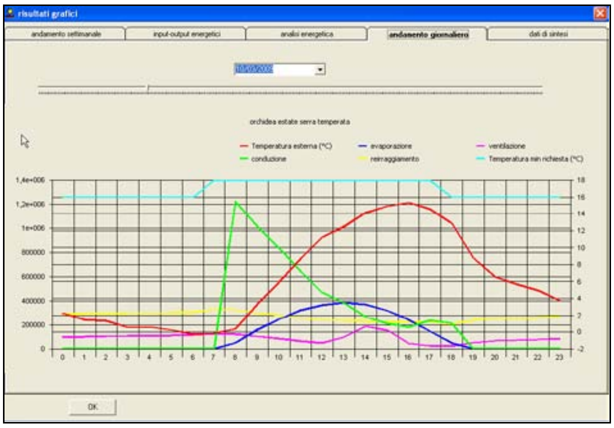


Fig. 5. Example of output provided by the model: external temperature, evaporation, ventilation, conduction, re-irradiation, minimum temperature required.

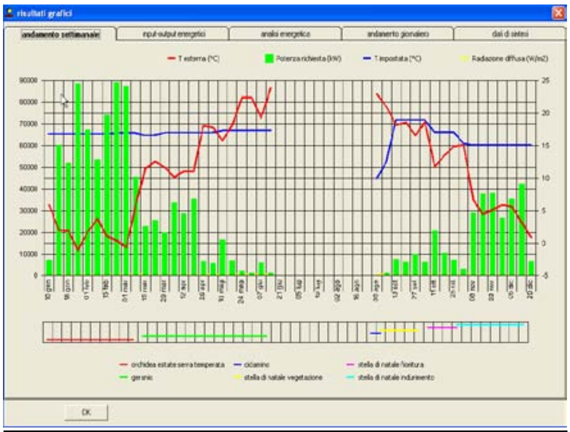


Fig. 6. Outputs by the model: external temperature, power required, set temperature, diffuse radiation.

At the present development of the software, one year of real data campaign collected by commercial greenhouses has been completed; the data will be used to validate the model in order to assess the software performance in providing solid correspondences between real and simulated conditions.

Conclusions

A Decision Support System to evaluate the energy requirements and the relevant cost in greenhouses for ornamental plants production has been developed. The program can be used as a guideline for improving energy efficiency by simulation of virtual greenhouses. The system has a potential to be widely used among greenhouse growers and manufacturers. For a better applicability, other modules need to be added such as water consumption, manpower need and crop quality.
Recommendations are given to the users in order to perform simulations with the real and intended characteristics of their greenhouse in order to evaluate the economic feasibility of improvements.

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