BIOCLIMATIC GREENHOUSE

ENERGY BALANCE OF A GREENHOUSE

The thermal balancing of a greenhouse is:

$$\dot{Q}_{cop} + \dot{Q}_{inf} + \dot{Q}_{irr.sol} + \dot{Q}_{cond} = 0 \qquad [W] \qquad (1)$$

$\dot{Q}_{cop}$ is the thermal power lost through the covering,
$\dot{Q}_{inf}$ is the thermal power lost by infiltration,
$\dot{Q}_{irr.sol}$ is the thermal power gained through solar radiation,
$\dot{Q}_{cond}$ is the thermal power required for the conditioning system.
Heat losses occur mainly by convection, conduction and irradiation through the greenhouse covering of area A_{cop}, they can be calculated using the transmission transmittance *U*:

$$\dot{Q}_{cop} = A_{cop} U (T_i - T_e) \qquad (2)$$

Where T_i and T_e are the internal and external temperatures.
The contribution of solar energy to the greenhouse can be expressed as:

$$\dot{Q}_{irr.sol} = \gamma \tau A_{esp} I \qquad (3)$$

Where:

- γ is the absorption coefficient of the greenhouse, it is between 0.3 and 0.7 and also depends on the crop;
- τ is the transmissivity of the greenhouse covering. Typical values are 0.55 - 0.70 for polymethacrylates, polycarbonate, single film and glass and 0.5 - 0.6 for double film;
- A_{esp} is the area of the greenhouse covering exposed to the sun;
- *I* is the intensity of global solar radiation.

In case of infiltration, the air current, which passes through cracks and / or openings in the greenhouse covering, is due to a pressure and / or temperature difference between inside and outside. As a consequence of this change of air there is a loss of heat, which can be expressed as the difference between the flow of outgoing and incoming heat:

$$\dot{Q}_{inf} = \rho n_L V_R c_p (T_i - T_e) \qquad (4)$$

Where c_p is the specific heat of air at constant pressure, n_L is a coefficient that depends on the wind speed and the tightness of the building, V_R the net volume of the building, ρ the air density.
From (1), (2), (3) and (4) we obtain from (1), (2), (3) and (4) we obtain the following for the thermal power the conditioning system must provide:

$$\dot{Q}_{cond} = A_{cop} U (T_i - T_e) - \gamma \tau A_{esp} I + \rho n_L V_R c_p (T_i - T_e) \qquad [W] \qquad (5)$$

The energy balance equation (5) shows the energy required for heating depends on the thermal properties building materials and structure of the greenhouse, and the gain of solar radiation. The idea behind the greenhouse model in the study conducted by Fail, illustrated in these pages, is to act on the various contributions of the energy balance. The thermal properties of the greenhouse, assuming an adequate airtightness and therefore low infiltrations of air, are summarized in the thermal transmittance of the covering *U*, equation (2). It is therefore necessary to adopt technologies and materials that lower the value of transmittance as much as possible.
Generally solar radiation is not used efficiently. During the day the incident solar radiation can lead to excessive internal greenhouse temperatures resulting in a thermal stress for the crops. In order to protect the plants it is often necessary to install a shading frame (external or internal) with a shading of 65/70% . A more efficient way of handling this excessive solar radiation is to store energy surplus in a heat storage system and to use it in passive air conditioning systems.

USE OF VACUUM TECHNOLOGY FOR GREENHOUSE COVERING

The study and tests on the skylight prototype carried out by Fail together with Convective Knowledge Soc. Coop. showed an extremely low transmittance value for a device that implements the vacuum technology. In the case of the skylight prototype tested, the transmittance reached a value of 0.8 W / (K * m ^ 2).
To apply this technology to a greenhouse, a cellular polycarbonate panel is being developed in which the vacuum has been made.
An alveolar polycarbonate panel has thermal and structural characteristics similar to the studied skylight and is considerably lighter than an extruded slab. Thanks to this lightness we can contain the weights of the greenhouse covering and of the structural frame. The polycarbonate panel used is heat-sealed and is equipped with a valve specifically designed for vacuum sealing.
As an example, the thermal power lost in the case of a 1m side cubic demonstrator is estimated. The values for the quantities in (5) used are:

$$T_i = 20°C;\ T_e = -5°C;\ V_R = 1m^3;\ n_L = 0.8h^{-1};\ A_{cop} = 5m^2;\ c_{p,aria} = 1.005\frac{kJ}{kgK}\ ;\ \rho_{aria} = 1.225\frac{kg}{m^3}$$

$$U_{vuoto} = 1.7\ \frac{W}{m^2K} \qquad (6)$$

Normalizing the value obtained for the cultivated area we have:

$$\dot{q}_{loss,vuoto} = \frac{\dot{Q}_{loss}}{A_{colt}} \cong 132\frac{W}{m^2}$$

For a more direct comparison we report the values of thermal power loss per unit of cultivable area for the polycarbonate panel with vacuum and some of greenhouse construction most used materials:

COVERING	U-VALUE W/(K*m^2)	THERMAL POWER LOSS Ti=20°C Te=-5°C W/m^2
Polycarbonate panel with vacuum technology Fail	1.7	219
glass	6,7	844
PE film	7,5	944
PVC film	5,5	694
PMMA	7	882
alveolar PMMA	2,9	369
alveolar PC	3,3	419
Double PE films with air	3,4	431

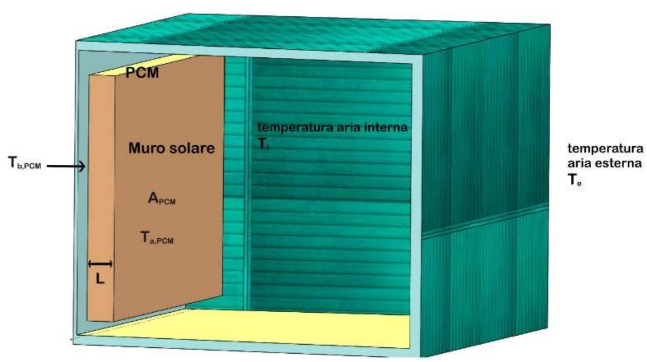
This preliminary analysis shows how the panel characterized by the vacuum practiced inside, allows a considerable reduction of thermal losses through greenhouse covering while retaining the optical properties typical of polycarbonate.

THERMAL ENERGY STORAGE WITH PHASE CHANGE MATERIALS (PCM) IN GREENHOUSE

In the literature there are many studies on the applications of thermal storage systems with PCM in buildings and greenhouses. These studies show that the presence of similar storage systems leads to a 40-50% saving on energy consumption for air conditioning. Different configurations have been experimented, with PCM inside solar concentrators, walls or pipes in the air recirculation system.

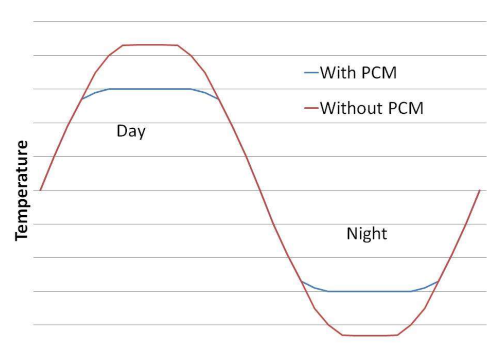
To manage the solar radiation more efficiently, we decided to develop a greenhouse prototype containing a solar wall as thermal accumulator that uses PCM. A solar wall is a collector for solar energy, usually is located in the most exposed part of the greenhouse, to the south for those in the northern hemisphere. The incident radiation is absorbed and stored to be used for the thermal comfort of the building. The stored heat can be used for heating in winter, during the night, or for cooling in summer, during the day.

This system consists of a wall made of a material with a high thermal storage capacity, a transparent surface that separates it from the outside (glass or other plastic material) and an air gap between the two (3 to 10 cm thick). The face of the wall exposed to light is painted black to increase the absorption of the incident radiation. On the solar wall as well as on the transparent surface can be made openings. These openings establish convective motions between the environment and the interspace or between the air space and the outside (air vents). Through these openings (vents) the solar wall can be adapted to the climatic needs of the season and/or of the day. So it can act as a heating element in cold climates and as a cooling element in hot climates.



The choice of the right transition temperature is of fundamental importance in using PCMs. For greenhouse applications this should be close to the ideal growth temperature of the crop.

In this way the accumulator wall will function as a thermal buffer, absorbing heat when the internal temperature exceeds this threshold and returning it at night when it will fall below (see figure at the side).



Another important parameter is the thermal diffusivity of the PCM:

$$\alpha = \frac{k}{\rho c_p} \qquad \left[\frac{m^2}{s}\right] \qquad (7)$$

In fact the time delay with which the PCM will return the accumulated heat and therefore the duration of the thermal accumulator discharge depends on the thermal diffusivity.

The following model has been developed for the use of a PCM storage system:

- The solar wall is considered a heat sink when $T_i < T_m$ dove T_m it is the melting temperature of the PCM, as a source when $T_i > T_m$;
- The external surfaces of the solar wall are at uniform temperature $T_{a,PCM}$ and $T_{b,PCM}$;
- The solar wall exchanges heat with the air inside the greenhouse by convection through its surface A_{PCM} (area of each of the two largest faces). This exchange is described by a convective transmission coefficienth_{PCM};
- The heat transmission inside the PCM takes place only by conduction;
- The transmission of heat within the PCM is considered as a one-dimensional problem in which the propagation direction is orthogonal to A_{PCM}, it takes place along the thickness L of the wall;
- The air temperature at the two sides of the wall is the same. This describes a solar wall with external vents closed and internal ones opened.

In this case we can write (5) as:

$$V_R c_{p,aria} \rho_{aria} \frac{dT_i}{dt} = \\ = \gamma \tau A_{esp} I - A_{cop} U (T_i - T_e) - V_R c_{p,aria} \rho_{aria} n_L (T_i - T_e) - A_{PCM} h_{PCM} \left(2T_i - T_{a,PCM} - T_{b,PCM}\right) \qquad (8)$$