16[èmes] Journées Internationales de Thermique (JITH 2013)
Marrakech (Maroc), du 13 au 15 Novembre, 2013

Etude de la Performance Thermique d'une Serre Agricole intégrant des Matériaux à Changement de Phase

Thermal Management of a Greenhouse integrated Phase Change Material

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Abstract: In this paper, the thermal performance of a north wall made with phase change material (PCM) as a storage medium in east-west oriented greenhouse is analyzed and discussed. $CaCl_2.6H_2O$ was used as a PCM. A numerical thermal model taken into account the different components of the greenhouse (cover, plants, inside air and north wall PCM) and based on the greenhouse heat and mass balance, has been developed to investigate the impact of the PCM on greenhouse temperature and humidity. Calculations were done for typical decade climate of January in Marrakesh (31.62° N, 8.03° W). Results shows that with an equivalent to 16.2kg of PCM per square meter of the greenhouse ground surface area, temperature of plants and inside air were found to be 8°C more at night time in winter period with less fluctuations. Relative humidity was found to be on average 10-15% lower at night time.

Key words: PCM, Greenhouse heating, north wall, Numerical analysis.

Introduction

Due to the high cost of energy, the use of alternative heating system is important for a greenhouse to provide optimum inside conditions during winter months. The basic strategy of greenhouse passive heating system is to transfer excess heat from inside the greenhouse during the day to heat storage. This heat is used during the night to satisfy the heating needs of the greenhouse. Several types of passive solar systems and techniques have been proposed and used in previous works [1-3]. The most important existing greenhouse heating systems are: water storage, rock bed storage, mulching, movable insulation and thermal curtain, ground air collector and north wall storage is also used for raising the greenhouse air temperature. For greenhouse located in northern hemisphere, East-West orientation is the most suitable, it favorites a maximum of solar radiations in winter and a minimum of solar radiations in summer. For East-West oriented greenhouse, a maximum solar radiation fall on the south wall during winter months and leaves the greenhouse through north wall. The sensible storage wall required high volume and temperature difference. The latent thermal storage has many advantages over the sensible one: high heat capacity, less volume, low storage temperature, thermal energy is stored and released at an almost constant temperature. The most frequently used PCM in greenhouse are $CaCl_2.6H_2O$ [4].

Mathematical Model

The phase change material north wall (PCM NW) of the greenhouse is insulated externally and internally received a fraction of total solar radiation transmitted to the greenhouse and has a radiative and convective heat exchange with the components of the greenhouse. Following assumptions were made: PCM is homogeneous and isotropic, the mode of heat transfer is conduction only, the convection is neglected (encapsulated PCM) and heat transfer is one-dimensional.

By using an enthalpy method, the energy equation in the wall reads as:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}(k\frac{\partial T}{\partial x}) - \rho \Delta H_m \frac{\partial f}{\partial t} \quad (1)$$

The last term takes into account the latent energy associated with phase change when they occur. The latent heat of melting is ΔH_m, f represents the liquid fraction of melt and it is given by:

$$\begin{cases} f = 1 \text{ if } T > T_m \\ f = 0 \text{ if } T < T_m \\ 0 < f < 1 \text{ if } T = T_m \end{cases} \quad (2)$$

T_m is the melting temperature of the PCM

Boundary conditions in the wall are:

- $x = 0$, interior surface of the PCM wall (facing the greenhouse as shown in figure 1):

$$\alpha_{sw} Q_w + h^c_{i,w} \frac{A_w}{A_g}(T_i - T_w) + h^r_{p,w} \frac{A_w}{A_g}(T_p - T_w) + h^r_{c,w} \frac{A_w}{A_g}(T_c - T_w) = -k \left.\frac{\partial T}{\partial x}\right|_{x=0} \frac{A_w}{A_g} \quad (3)$$

Al the fluxes of heat are expressed per m^2 of ground area of the greenhouse.

- $x = L$, exterior surface of the wall:

$$\left.\frac{\partial T}{\partial x}\right|_{x=L} = 0 \quad (4)$$

Thermo-physical properties of the PCM are evaluated as:

$$k = f\, k_l + (1-f)\, k_s, \quad \rho c_p = f\, (\rho c_p)_l + (1-f)\, (\rho c_p)_s \quad (5)$$

For selecting the PCM for the north wall, the following desirable's properties of $CaCl_2.6H_2O$ were taken into account: high latent fusion per unit mass, chemical stability, melting in the desired operating temperature range, small volume change during phase transition, availability in large quantities and low price. The north wall was filled with 388.8kg of $CaCl_2.6H_2O$. To mathematically describe the thermal behavior of the greenhouse components (cover, inside air and plants), equations are given in a previous paper [5].

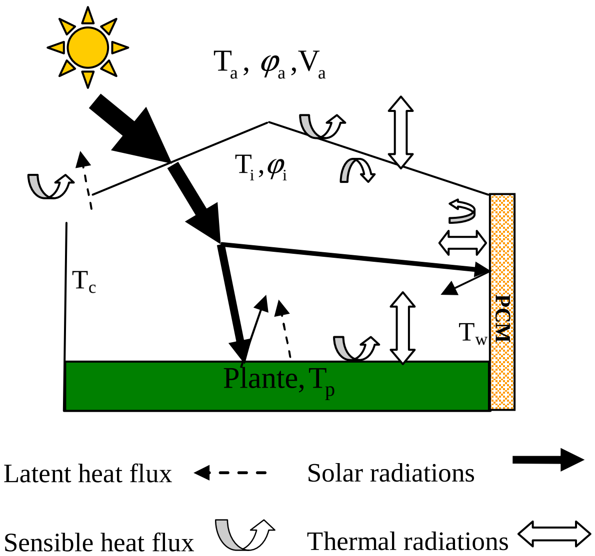
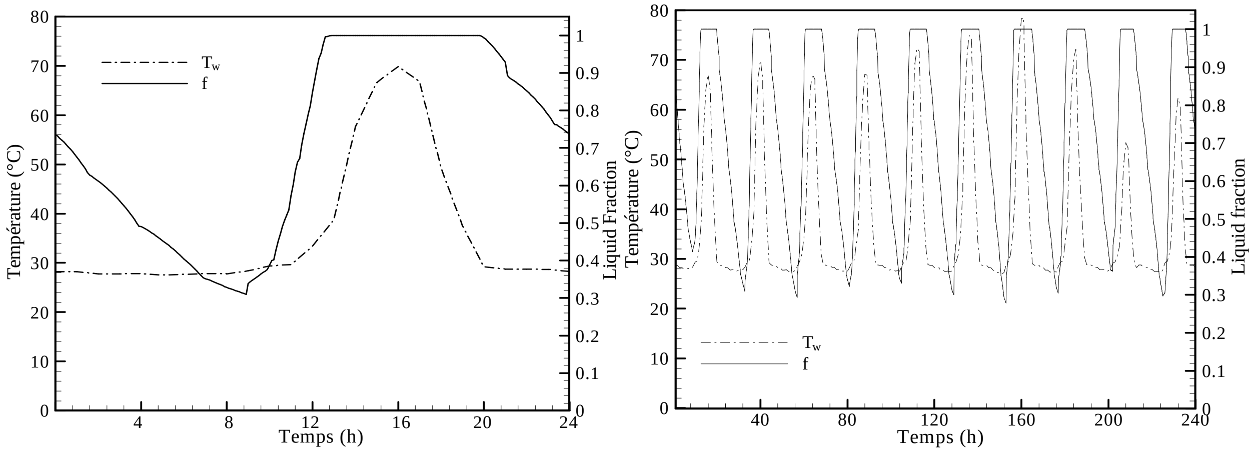


Figure 1: Energy balance of greenhouse components

Results

Analysis for the figure 2 shows that liquid fraction increase during the morning (from 9h to 11h) due to the increasing incident solar radiations and the wall temperature remains overly unchanged, because all the energy transmitted to the wall is completely used to melt the PCM as a latent heat of fusion. After these period (from 11h to

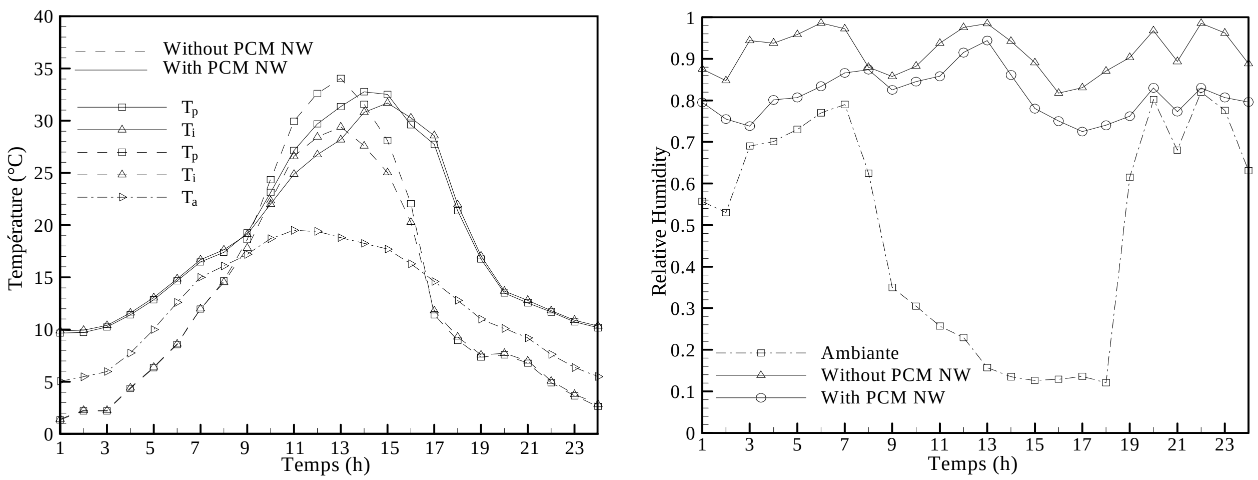
13h), wall temperature start increasing due to the activation of the sensible heat storage and leads to a rapid melting of PCM and liquid fraction reaches 1 at 13 h, but solar radiation persists after 13h, what leads to an overheating of the liquid PCM layer (Tw = 54°C at 17h). After 17h, solar radiation disappears, outside air temperature decrease and consequently the inside greenhouse temperature decrease. Heat transfer changes the direction from the wall (hotter medium) to the inside greenhouse (cold medium). Liquid PCM and wall losses their heat but liquid fraction remains unchanged (f =1) because the liquid PCM was superheated (sensible heat storage). After about 20h liquid fraction begins to decrease (solidification or discharging period) and we remarks that the wall temperature remains relatively constants (latent heat of fusion) until the morning (9 h). It was observed that during the night, wall temperature never falls down (28°C) when the outside air temperature drop until 5°C. The north wall incorporating PCM plays the role of a heat sink during the day and a heat source during the night. The energy stored during the day is released at night. Approximately, the same trend was observed during the other days of the typical climate decade of January in Marrakesh, figure 2 (b), which leads to a passive heating of the greenhouse.



(a) (b)

Figure 2: Hourly variation of the liquid fraction and the temperature of the north wall for a typical climate day (a) and for the typical decade climate of January in Marrakesh (b).

The nocturnal variation of temperature for the greenhouse with the PCM NW were observed to be on average 8°C higher for plants and inside air, figure 3 (a). This period corresponds to the discharge process of the PCM (solidification) and as it was mentioned above the wall temperature remains approximately unchanged (T_m = 29°C). The wall can be considered as a heat source and the heat is transferred to the greenhouse components (plants, inside air and cover) by convection and radiation. This creates a healthy environment of plants during winter period.



(a) (b)

Figure 3: Hourly variation of the inside temperature of greenhouse with and without PCM NW for a typical climate day of January in Marrakesh (a) and relative humidity (b).

The greenhouse air relative humidity was maintained 10-15% lower as compared to the relative humidity in conventional greenhouse, figure 3 (b). The PCM system is able to create a passive dehumidification process especially at night time due to the increase in inside air temperature.

Conclusion

For east-west oriented greenhouse, maximum solar radiations falls on the south wall during winter months and a fraction of this solar radiations leaves the greenhouse through north wall. Therefore, a phase change material north wall is proposed in this study for absorption and reflectance of solar radiations. During the day time, incident solar radiations on the wall raise its thermal storage. This stored energy is realized to the greenhouse by convection and radiation. From the present study, the following conclusions can be drawn:

- There occurs on average a 8°C rise of plants and inside air temperature at night time due to the use of a 2cm thick PCM NW as a storage medium.
- Relative humidity is 10-15% lower in a greenhouse with PCM NW.

Nomenclature

A_g	ground area of the greenhouse (m^2)	$h^c_{w,i}$	convective heat transfer coefficient between the inside air and the wall $(W\,m^{-2}K)$
A_w	north wall surface (m^2)	k	thermal conductivity of the PCM $(W\,m^{-1}\,K)$
c_p	specific heat of PCM $(J\,kg^{-1}\,K^{-1})$	L	thick of the wall (m)
$h^r_{c,w}$	heat transfer coefficient due to long wave radiation between the cover and the wall $(W\,m^{-2}K)$	Q_w	Solar radiation incident on the wall $(W\,m^{-2})$
		α_{sw}	Absorptivity of the wall to solar radiation

References

[1] M. Santamouris, G. Mihalakakou, C.A. Balaras, J.O. Lewis, M. Vallindras, A. Argirious, Energy conservation in greenhouses with buried pipes, Energy 21 (5) (1996) 353–360.

[2] J.R. Barral, P.D. Galimberti, A. Barone, A.L. Miguel, Integrated thermal improvements for greenhouse cultivation in the central part of Argentina, Solar Energy 67 (1–3) (1999) 111–118.

[3] M.N. Bargach, R. Tadili, A.S. Dahman, M. Boukallouch, Survey of agricultural greenhouses in Morocco, Renewable Energy 20 (2000) 415–433.

[4] M. Kern, R.A. Aldrich, Phase change energy storage in a greenhouse solar heating system, ASAE Paper No. 79-4028, Am. Soc. Agric. Eng., St. Joseph. MI. (1979).

[5] F. Berroug, E.K. Lakhal, M. El Omari, M. Faraji et H. El Qarnia, Thermal performance of a greenhouse with phase change material north wall, Energy and Building 43 (2011) 3027-3035.