SIMULATION OF SOLAR DRYER FUNCTIONING IN A MOROCCAN CLIMATE

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Abstract

The main of this work is to simulate the operation of wood solar dryer. A mathematical model taking account of real atmospheric conditions: ambient temperature and insolation is developed to simulate operation of simple but efficient solar dryer in a Moroccan climate.

The model is validated by comparing numerical values to experimental measurements carried out in moderate Moroccan climates. Numerical results show that drying period is closely linked to glass partitions. Nature of ventilation has no effect on drying period (initial timber humidity lower than 40 %).

KEYWORDS

Solar, drying, climate, wood, simulation

1. INTRODUCTION

In Morocco, plantations of various wood types represent an important area. Most part of these reafforestations are used as (serves for) fire wood, paper paste. However, some of these varieties are highly requested for their attractive qualities, so for their using in decoration and joinery. A artificial statistical study about drying systems of wood in Morocco [1], shown that only 13 firms use (electricity) dryers. The annually dried volume of wood in sawing and joinery activities is about 8000 m^3, that is less than 2,7% of total volume processed by these activities. The other part of wood is dried in open air (natural drying).The man reason that prevents (stops) firms working wood from using an artificial dryer are the high cost of these systems.

On the other hand, Morocco have an important solar potential, an average incident solar energy from 4.7 $kW \cdot h \cdot m^{-2}$ to 5.7 $kW \cdot h \cdot m^{-2}$ daily [2]. Thus, the solar drying can be a way of development of wood drying in our country. Indeed, experimentations studies [3-7] showed that solar drying allows better quality (less cracks) and fast drying than the open air (drying period lower). Solar drying is normally more expensive to operate than air drying, but is always cheaper and easier to operate than conventional kilns.

The aim of this work is to present a numerical simulation of simple, but efficient solar dryer working in Mediterranean type Moroccan climate: Rabat, to study its characteristics. The objective is to provide Moroccan craft industry with competitive solar dryer.

We choose ‘thuya’ as resinous timber to dry because of its abundance in Morocco [8-10] and its using in decoration and joinery.

The calculations are carried out to reach 15 % of timber humidity from an initial humidity equal to 35 %, about point of fibres saturation humidity. We opt for this value of initial humidity (35 %), because most part of water can be taken off easily and quickly from timber when its humidity is upper than 35 % (free water: aqueous part of timber). In Rabat, were average values of humidity and ambient temperature are respectively about 75 % and 20 °C, the drying or final humidity is 15 % [11].

2. SOLAR DRYER DESIGN

We simulate operation of greenhouse dryer type of 1,5 m^3 of capacity. The roof and 3 walls are transparent glazing (6 mm thick glass): south, east and west. The roof is south facing and sloped by 25° from the horizontal (about value of latitude of Rabat) [2]. The absorber, aluminium black painted placed over the wooden pier, constitute a false ceiling. Above is placed a ventilator to ensure air circulation. North side is isolated and contains a door. The air evacuation is ensured by vents (opening) manually operated.

Experimental works has been carried out as studies of memorandum in last year of engineering school of Rabat University [3, 4]. In this paper, we simulate the operation of same type of dryer used in experimental works for following objectives:

1. to study the behaviour of dryer in same type of climate to validate our numerical model,
2. think to other types of dryers to make solar drying systems competitive,
3. to adapt solar dryers to Moroccan climates.

3. SOLAR DATA

The atmospheric conditions are related to Rabat site: coastal town of 34° north latitude and longitude equal to 7° west. Data concern ambient temperature, solar radiation and relative humidity of June 2000.

In Figs. 1, 2, we represent variation of ambient temperature and solar radiation during a day of June in Rabat.

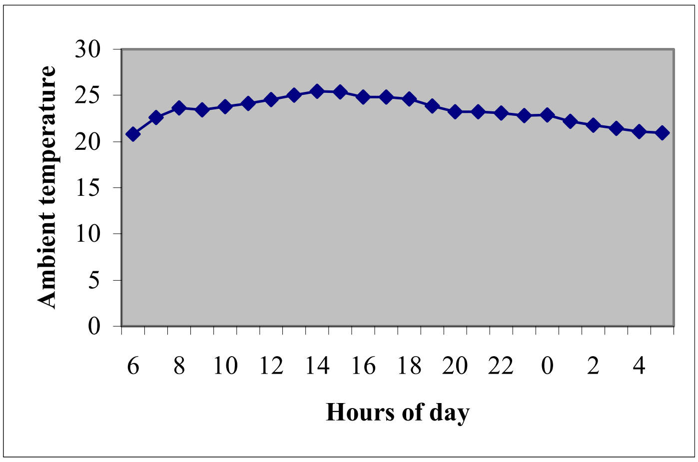

Fig. 1. Evolution of ambient temperature

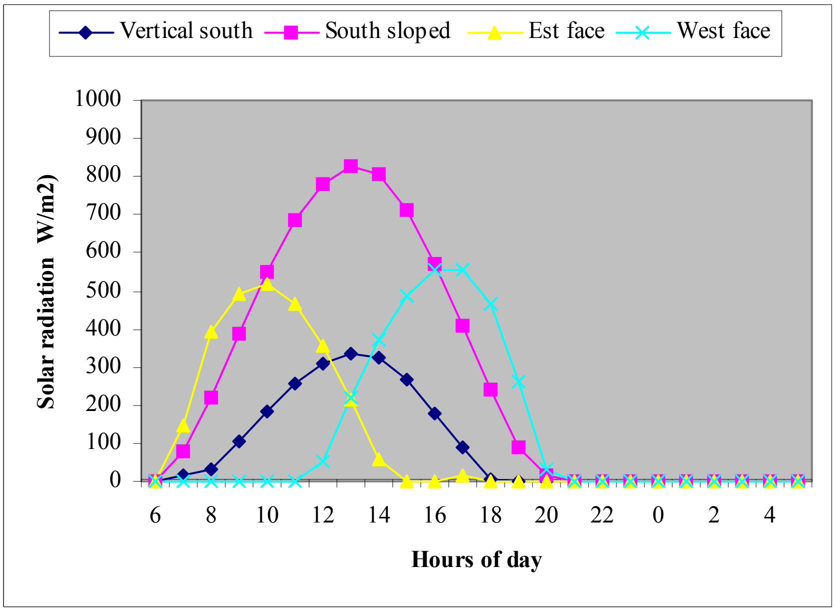

Fig. 2. Evolution of solar radiation in Rabat

4. MATHEMATICAL MODEL

Inside drying room (1.5 m^3), we take account of heat and mass transfer. The model describe evolution of temperature, timber humidity and air humidity inside drying room. The timber thickness is about 27 mm.

4.1. Mass transfer

The timber humidity (X %)is defined by ratio between water mass ($m - m_0$) and timber dry mass m_0.

$$X\,\% = \frac{m - m_0}{m_0} \cdot 100\,\%\,, \tag{1}$$

where m is humid mass of timber.

While the value of timber humidity is higher than its equilibrium humidity X_e, the moving of water from the upper humid zones (centre) to zones with least humidity (surfaces). This moving is given by the following equation:

$$m_0 \frac{dX}{dt} = -K\rho_0 S(X - X_e)\,, \tag{2}$$

where K, coefficient of water moving in timber, is characteristic of wood. This coefficient is inversely proportional to timber dry density of timber ρ_0 ($\rho_0 = \frac{m_0}{Se}$) [12],

S is timber surface, ρ_0 its dry density and e its thickness.

To take account of the water evaporation from surface of timber to surrounding air (not waterlogged) J. Taylor [13] propose the relation:

$$\frac{dX}{dt} = -fK\left(X - X_e\right)/\,e\,, \tag{3}$$

where f is a saturation coefficient given by:

$$f^2 = (Y_s - Y)/(\overline{Y_s} - \overline{Y}), \tag{4}$$

where Y and Y_s are respectively absolute and saturation humidity. $\overline{Y}$ and $\overline{Y_s}$ are their average values during drying period.

4.2. Humidity inside drying room

Air exchange between drying room when it is open.

When is open, drying room, exchange air with outside. The evolution of humidity is given by

$$\frac{dYi}{dt} = -\frac{Q}{V}\left(Y_i - Y_e\right) - \frac{m_0}{V}\left(\frac{dX}{dt}\right), \tag{5}$$

Q is debit of volume that enter and exit from drying room of volume V (1.5 m^3),

Y_i and Y_e are absolute values of humidity inside and outside dryer.

4.3. Heat transfer

The energy balance is

$$\frac{dT_i}{dt} = \frac{1}{\left(m_b c_b + m_s c_s\right)}\,[\tau\alpha(S_o E_o + S_{ea}E_{ea} + S_i E_i + S_v E_v) - S_n K_n \cdot (T_i - T_e) - S_{sol}K_{sol}(T_i - T_e) -$$

$$-Q\left[(Y_i - Y_e)Lv - \rho_a c_a (T_i - T_e)\right] + W_v\,], \tag{6}$$

Q is the volumetric flow rate of air into and out of the dryer (through the vents).When the dryer is closed, $Q = 0$;

S represents surface, with suffix: ea – east, o – west, v – vertical, i – inside the dryer, e – outside, sol – soil; E is solar energy.

The first term represent the energy received by dryer from solar radiations.

Second and third terms (preceded by minus sign) represent losses by glass faces and the soil.

$Q[(Y_i - Y_e)Lv - \rho_a c_a (T_i - T_e)]$ takes account of latent and sensible heat of air flow,

W_v represents the heat dissipated by the fan.

$S_n K_n$ $(T_i - T_e)$ represent loss through glasses faces, where S_n and K_n are respectively glass surface and global transfer coefficient through the glass.

5. SIMULATION

We have a three equations system. Finite differences method is used to calculate temperature, humidity inside dryer an timber humidity.

6. RESULTS

Evolution of hourly values of temperature inside dryer (Fig. 3) shows that temperature average is about 40 °C. This result is also obtained by experimental study in Moroccan sites [3, 4].

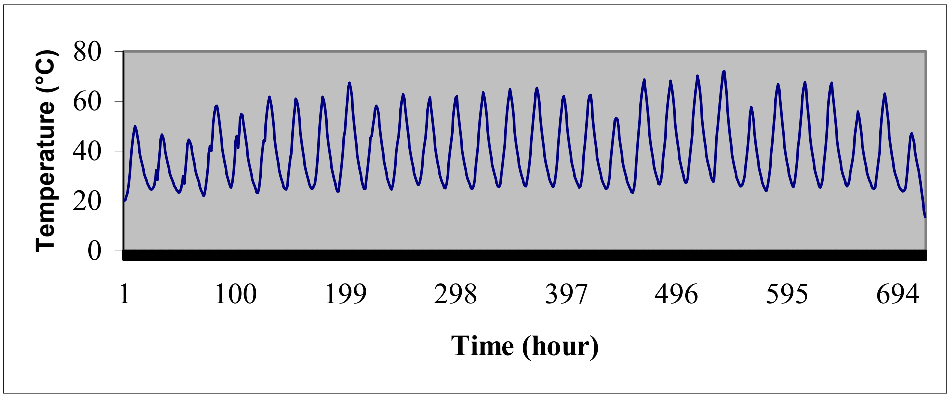

Fig. 3. Evolution of temperature inside dryer

The Fig. 4 giving hourly absolute humidity variation inside drying room, shows that values reach 1.2 kg·m^{-3} in beginning of drying period, then it falls when we open dryer (between 12h and 16h) to attain the exterior humidity (0.0015 kg·m^{-3}). We notice in that the humidity decrease from one day to the next to reach 0.05 kg.m^{-3} at the end of drying time.

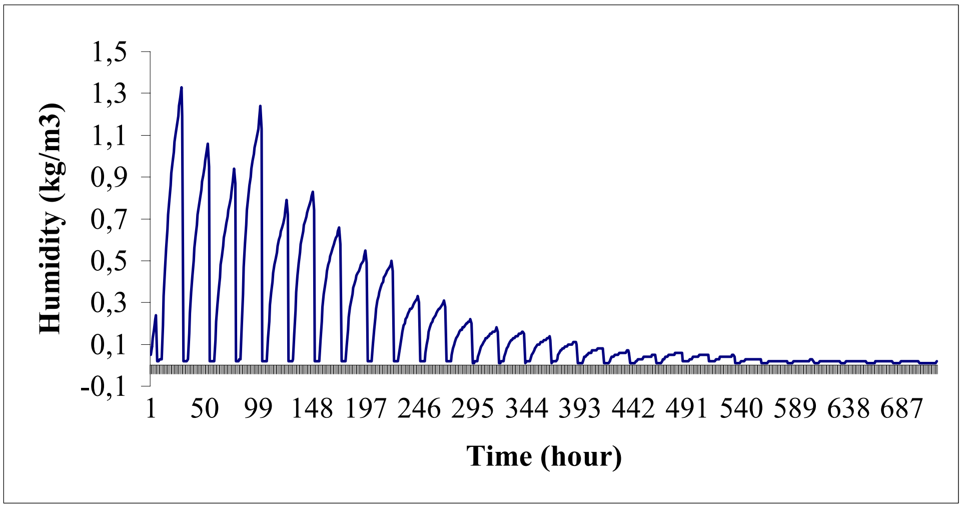

Fig. 4. Evolution of humidity inside

Figure 5 gives timber humidity evolution versus time and show that values decrease in time to reach 15 % in period of 20 days.

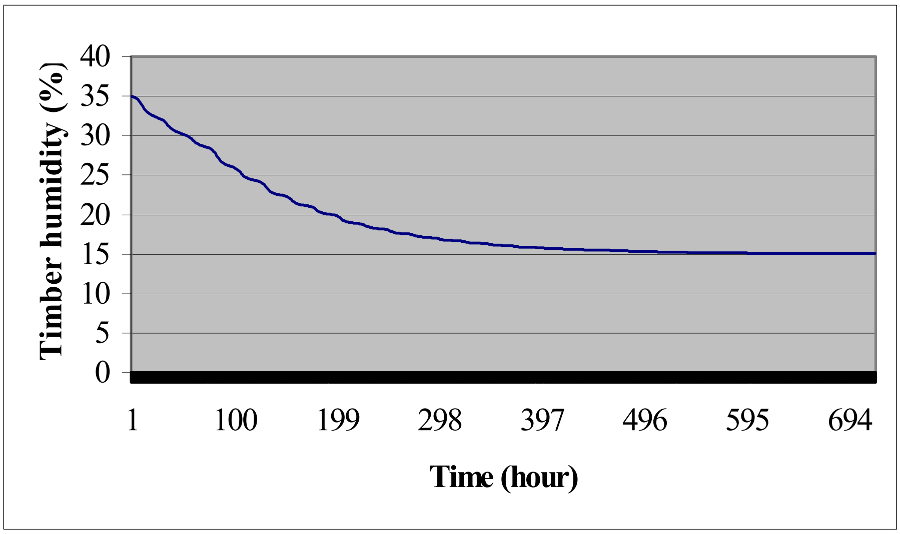

Fig. 5. Variation of timber humidity

7. VALIDATION OF SIMULATION MODEL

Experimental dryer [4] permits to timber (27 mm) to attain 14% of humidity from initial humidity equal to 34% , in period of 22 days, in moderate climate site of Morocco. The same results are given by measurement of an other experimental study [3].

We conclude that results given by measurements [3, 4] and the present work are in agreement.

8. PERFORMANCES OF DRYER

Temperature inside drying room has an important role in the drying kinetic. To optimise conditions of kinetic drying, most parameters can intervene (glass nature, insulation, ventilation, thickness) in given site. In this work, we take account of glass nature and ventilation.

8.1 Glass effect

We use three types of glasses:

1. Simple glass: the dryer transparent faces are of simple glass thick of 6 mm and have a global transmission coefficient equal to 6 $W\cdot m^{-2}\cdot K^{-1}$.
2. Double glass which permits to have transmission coefficient about 3.15 $W\cdot m^{-2}\cdot K^{-1}$.
3. Simple glass painted with mince thickness of polyethylene; the transmission coefficient is 4 $W\cdot m^{-2}\cdot K^{-1}$ [12].

In Figure 6 we represent timber humidity in versus time for the three types of glasses. We notice that when double glass is used, drying period is reduced to 50 % comparatively to simple glass. Polyethylene system permits to diminish period to 40 %.

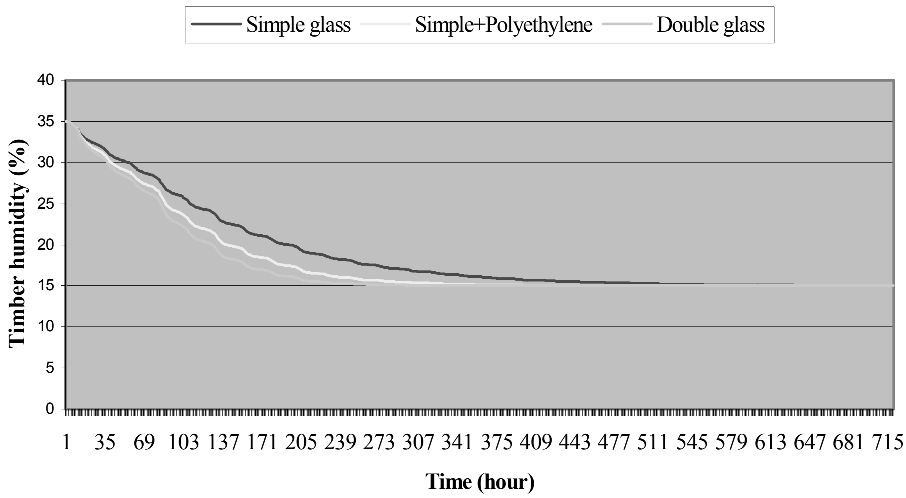

Fig. 6. Evolution of timber humidity for different types of glasses

8.2. Ventilation effect

In practice, ventilation is swished only during day where humidity can reach high values, this to reduce electricity consummation. La figure 7 gives the evolution of timber humidity of three types of ventilation: ventilation turns day between 6 am and 7 pm, between 12 (noon) and 4 pm and without ventilation. In all cases, vents placed on north wall are open between 12 and 4 pm, to remove moist air from the dryer.

We note that the effect of ventilation on drying time is negligible. Indeed, when the initial humidity of timber is lower that 40 %, the ventilation has no effect on drying period [11, 14], but the air velocity inside dryer is important for homogeneity of drying conditions. Consequently, the second type of ventilation, used when degree of moisture is important in the drying room and consuming less energy that the first one is recommended.

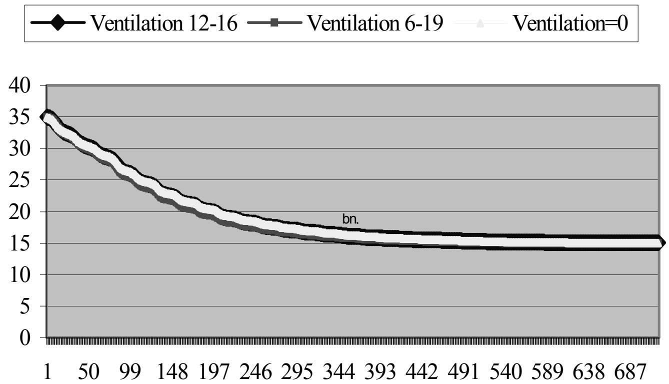

Fig. 7. Evolution of timber humidity for three types of ventilation

CONCLUSION

Numerical results show that drying period of thyua in moderate Moroccan climate is of 20 days, from initial timber humidity equal to 35%. This period is reduced to half when we use double glass for transparent faces. Ventilation has no effect on drying period. To remove air moist from the dryer and to homogenize drying conditions, it is recommended to use ventilation taking vents open for four hours a day (12 – 4pm).

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