Energy performance study of a direct solar dryer installed under sub humid region

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Abstract

In this work a new approach for modeling the energy behavior of a direct solar dryer is developed. On the one hand, we used a detailed formulation to calculate accurately the various solar fluxes intercepted by dryer cover to develop a numerical model, and on the other hand, we considered the experimental results obtained using a solar dryer prototype, constructed and operated in the Solar Energy and Environment Laboratory and equipped with measuring instruments. We used hourly measurements of the global solar radiation incident on horizontal surface and the global solar radiation transmitted inside the dryer. Measurements were carried out in the city of Rabat in Morocco. The geometry effect of solar dryer on the daily intercepted solar energy profile was determined. Analysis of this effect allowed us to consider multiple geometric scenarios of the solar dryer, leading to choose an optimal structure able to receive and to transmit a maximum of daily solar energy, while the underlying performance calculation model not exceeding 6 % error in comparison with data measurements.

Keywords: *Solar dryer, Global solar radiation, Transmitted solar radiation, Numerical model, Cover transmitted coefficient, Geometric scenarios*

1. Introduction

In this study we used hourly values of the incident horizontal global solar radiation I_{gh}, and the transmitted one inside the dryer I_{gh}. Both components, corresponding to a clear climatic condition are measured on 16th July 2012 in Laboratory of Solar Energy and Environment in Rabat location (latitude $\phi = 34° N$) [1]. The object is to determine the impact of the solar dryer geometric shape on the profile variation of the global radiation, transmitted by the dryer cover. The analysis of this impact brings towards an optimal structure scenario that will be able to receive and to transmit a maximum of daily energy with an error not exceeding 6 %.

2. Modeling of solar radiation flux densities of the glazing

The glass cover behavior towards the received radiation depends on its radiative properties [2] that varies with:

- **The wavelength of the radiation:** the glass is transparent to visible radiation of wavelengths between 0.4 and 0.7 μm, and opaque to infrared radiation of wavelengths greater than 0.8 μm.
- **The direction of the incident radiation:** for normal incidence, the simple untreated walls surfaces let penetrate between 85 and 90 % of incident solar radiation; for various incidence angle, these values will be different, and will be defined as a function of the angle of incidence θ.
- **The spectral composition of the incident radiation:** in the optical spectral range, we consider that the spatial distribution of light in the sky is anisotropic; the glass properties will be then different depending on spectral direct or diffuse radiation.

3. Case of direct solar radiation

We define the spectral coefficients of direct solar radiation $\alpha_b(\theta)$, $\rho_b(\theta)$ and $\tau_b(\theta)$ by the report of the absorbed, the reflected, and the transmitted solar flow, and the incident solar flow respectively. Theses coefficients satisfy the following relation:

$$\alpha_b(\theta)+\rho_b(\theta)+\tau_b(\theta)=1 \quad (1)$$

The variation of theses coefficients is generally low for incidence angles between $\theta = 0°$ and $\theta = 45°$. The figure 1 shows the variation of theses coefficients for an ordinary glass with 6 mm of thickness [3]:

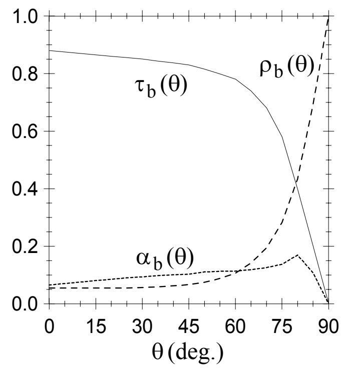

Figure 1. Variation of the transmission $\tau_b(\theta)$, the reflection $\rho_b(\theta)$ and the absorption $\alpha_b(\theta)$ coefficients vs. a function of incidence angle θ of the direct solar radiation.

As the glass thickness of the solar dryer is 6 mm, the values of theses coefficients are adopted in our study.

4. Case of diffuse solar radiation

The diffuse radiation distribution is generally unknown or variable in time. In this work, the adopted values of the diffuse absorption, reflection and transmission coefficients $\alpha_d(\theta)$, $\rho_d(\theta)$ and $\tau_d(\theta)$, respectively, are considered constant and estimate from the direct corresponding ones for θ equal to 60° [4].

5. Formulation of solar radiation flux densities

Crossing the earth's atmosphere, solar radiation undergoes changes due to the presence of gas molecules and solid or liquid particles suspended in the air. Once on the ground, it will consist of three components: direct radiation $I_{b\beta}$, diffuse radiation $I_{d\beta}$ and reflected radiation $I_{r\beta}$. The sum of these three components is the global solar radiation $I_{g\beta}$. Formulas required to evaluate the solar radiative flux densities are expressed in [5], [6] and [7].

6. Results and discussions

To study the energy behavior of the dryer, in response to climatic conditions of the installation location, we used us input data, the hourly measurements of global solar radiation incident on horizontal surface, carried in Rabat city during the 16th of July 2012. The following figures 2 a, b, c and d show the evolution related to this day of the total global solar radiation $I_{g\beta t}$ incident on the transparent cover (dashed curve), compared to the incident global radiation $I_{g\beta i}$ for each façades S_1

(with β tilt toward south), S_2 *(vertical toward south)*, S_3 (*vertical toward east*) and S_4 *(vertical toward west)* (figure 2):

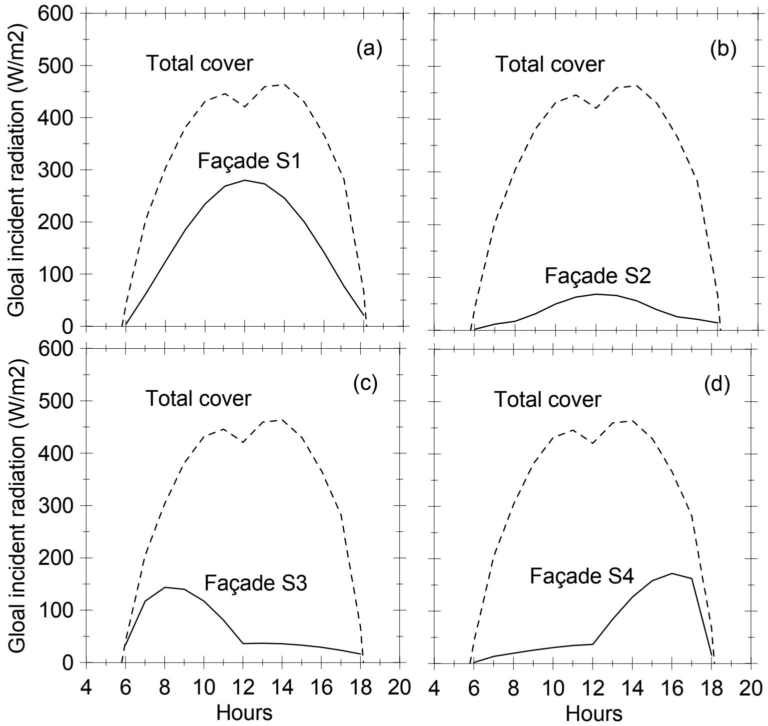

Figure 2. Comparison between incident global solar radiation on the total cover glazing (dashed curve) and the façades S_1 (a), S_2 (b), S_3 (c) and S_4 (d) (solid curve).

Two observations arise from these curves:

- The profile of the global radiation received by each facade is different because of the face geometry;
- The variation profile of the overall total radiation incident on the cover is deformed at the midday due to the overlap of the incident radiation on each surface.

To study the impact of the geometric shape on the profile variation of the global radiation $I_{g\beta t}$ incident on the cover, we associate the dryer to an orthogonal *(Oxyz)* reference, whose axes are respectively parallel to the three edges of the dryer. For this reason we varied, in the first step, a dimension of the dryer from the standard geometry and in only one direction at a time. The other dimensions remain constant (figure 3).

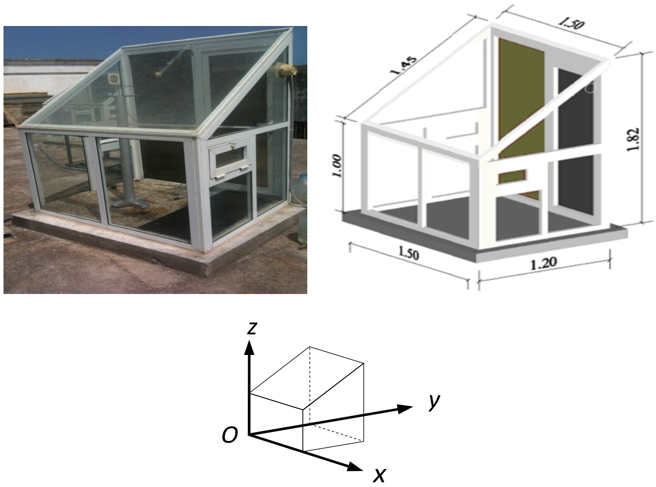

Figure 3. Dimensions (in meter) of the standard geometry of the prototype dryer installed on the terrace of the laboratory.

The shape transformations of the cover are schematized in the figure 4:

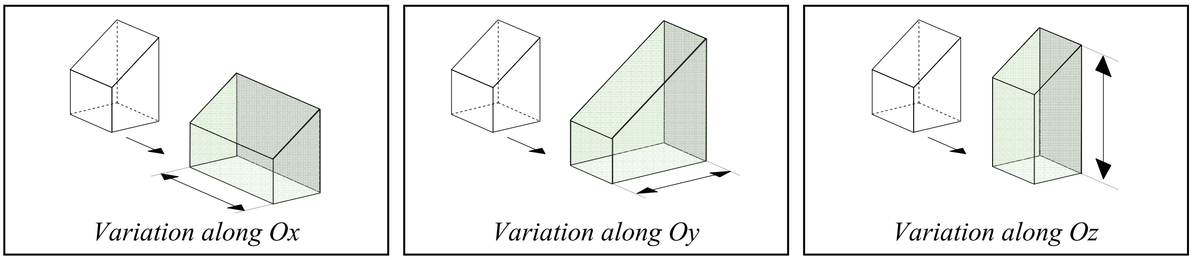

Figure 4. Shape transformations realized from the standard geometry along the three directions of the dryer.

During the studied day, the variation profile of the global solar radiation incident on the standard cover (dotted lines), compared to the global solar radiation incident on the modified cover (solid lines): (a) along *Ox*, (b) along *Oy* and (c) along *Oz*, is illustrated by the following curves (figure 5):

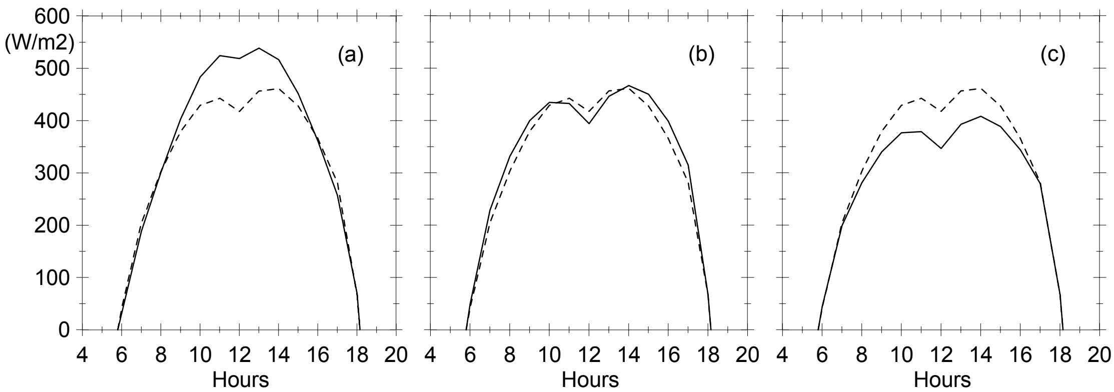

Figure 5. Comparison of the variation profile of incident global solar radiation on the standard cover (dotted lines), and the global solar radiance incident on the modified cover (solid lines).

This comparison shows that the daily energies received by geometries (a) and (b) are greater than the energy received by the standard geometry (see table 1).

Table 1 Daily energy received by different geometry cases

Geometry	Standard	a	b	c
Daily energy (kwh/m²)	4.274	4.642	4.411	3.843

In order to study separately the impact of each dimension on the variation of the received energy, we fix in a second step the dimensions of the dryer along *x* and *y* directions at their respective standard values ($x = 1.5$ m and $y = 1.2$ m).

6.1 Variation along the z direction:

We calculate then the total daily global solar radiation incident on the dryer cover by varying gradually the height *z* from 0 m to 5 m. The figure 6 shows that, for $z \approx 0$, the maximum daily energy reached is 5.777 kWh/m^2. The variation of the daily energy is strictly decreasing as a function of height *z*: rapidly for small values of *z* (26 % between 0 and 1 m), and slowly for larger values of *z* (2.3 % between 4 and 5 m).

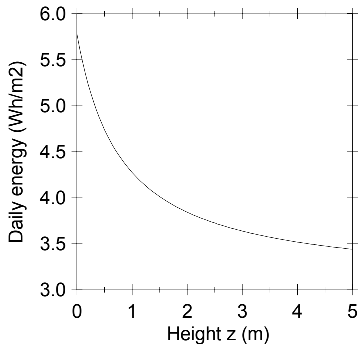

Figure 6. Daily received energy as a function of the height.

From a strictly energetic viewpoint, the choice of standard height $z = 1$ *m* used for the experimental dryer is not the best. However, for practical reasons, this height is valid because a minimum space should be arranged to install the product to dry. It is therefore estimated that the height $z = 1$ *m*, which provides a good compromise between the optimum energy that's may be recovered and the space needed, is acceptable and will be adopted in the following.

6.2 Variation along the x direction:

In the same way, we varied the length of the dryer along the *x* direction from 1 to 10 m. For each value of *x*, we then varied the width of the dryer along the *y* direction. We calculate each time the total daily energy received by the cover. We note, for a fixed value of *x*, that the daily energy E_{qt} increases with *y* until it reaches a maximum value E_{qtm} for $y = y_m$, and then decreases.
In the figure 7, we represent the variation of E_{qt} according to different values of *x*.

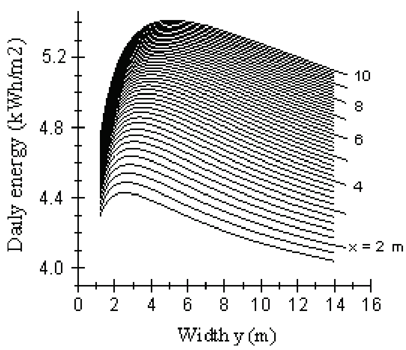

Figure 7. Daily received energy as a function of the width *y* according to different values of *x*.

By linking the y_m points belonging to the different curves $E_{qt} = \text{f (y)}$, we obtain the following curve representing the variation of the maximum daily energy E_{qtm} corresponding to the optimal width of the dryer y_m (Figure 8). This approach leads to better optimize the energy transmitted to the dryer taking into account simultaneously the (x , y) couple values [8].

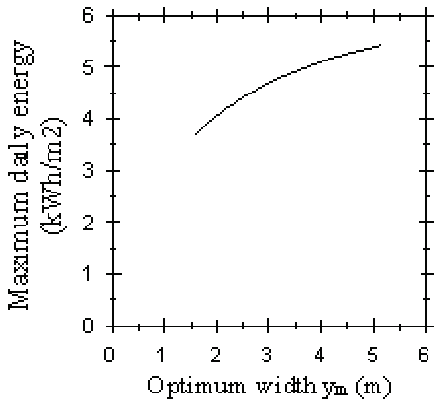

Figure 8. Daily received energy as a function of the optimum width y_m.

It is clear from this curve that a significant increase in the size of the dryer along y direction does not results in a large increase in daily energy received. An increase of this energy beyond $y = 7$ or $8\ m$ is not significant.

The daily energy surface E_{qt}, obtained simultaneously for different values of x and y is given by the figure 9:

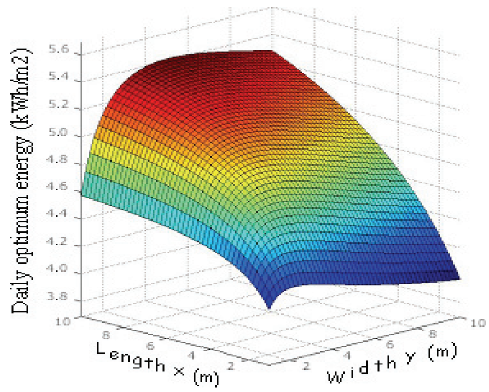

Figure 9. Surface of the daily optimum energy for different values of x and y.

At first sight, we note that the more x increases, the more important is the daily received energy E_{qt}. This is explained by the fact that the increase in x causes the increase of the surfaces S_1 and S_2 that are oriented toward the South, and consequently receiving and transmitting more energy.

7. Conclusion

In this study, we tested several geometric configurations around a standard form of a prototype dryer installed and tested under the climate of Rabat. The results show that the choice of a minimum height z of 1 m provides a good compromise between the optimum daily energy and the sufficient space to satisfy the practical usefulness of the dryer. The study showed also that the energy received and transmitted by the dryer is more important with large values of x length. The choice of x remains linked to the project budget and its objectives. The y width of the dryer can be then determined from table given in appendix A. Standard geometric shape that we used for our study was inspired from several designs represented in the literature [9] and [10], where the geometric aspect has not been sufficiently developed. However, the study that we conducted focused on this side and showed that the optimum geometry of the dryer helps in increasing the solar energy transmitted into the dryer and therefore enhance solar drying conditions [11].

APPENDIX A

Table A1 Maximal daily energy corresponding to optimal width and length.

x (m)	*y (m)*	E_{qt} *(kwh/m²)*	*x (m)*	*y (m)*	E_{qt} *(kwh/m²)*	*x (m)*	*y (m)*	E_{qt} *(kwh/m²)*
0.1	1.57	3.690	3.5	3.32	4.843	6.9	4.37	5.218
0.2	1.65	3.770	3.6	3.36	4.859	7.0	4.39	5.225
0.3	1.74	3.843	3.7	3.39	4.874	7.1	4.42	5.233
0.4	1.81	3.909	3.8	3.43	4.889	7.2	4.45	5.240
0.5	1.88	3.970	3.9	3.46	4.903	7.3	4.47	5.248
0.6	1.95	4.026	4.0	3.50	4.917	7.4	4.50	5.255
0.7	2.02	4.078	4.1	3.53	4.931	7.5	4.53	5.262
0.8	2.08	4.127	4.2	3.56	4.945	7.6	4.55	5.269
0.9	2.14	4.173	4.3	3.60	4.958	7.7	4.58	5.276
1.0	2.20	4.216	4.4	3.63	4.970	7.8	4.60	5.283
1.1	2.26	4.256	4.5	3.66	4.983	7.9	4.63	5.290
1.2	2.32	4.294	4.6	3.70	4.995	8.0	4.65	5.297
1.3	2.37	4.331	4.7	3.73	5.007	8.1	4.68	5.303
1.4	2.42	4.365	4.8	3.76	5.019	8.2	4.70	5.310
1.5	2.47	4.398	4.9	3.79	5.030	8.3	4.73	5.316
1.6	2.52	4.429	5.0	3.82	5.041	8.4	4.75	5.322
1.7	2.57	4.459	5.1	3.85	5.052	8.5	4.78	5.328
1.8	2.62	4.488	5.2	3.88	5.063	8.6	4.80	5.335
1.9	2.67	4.515	5.3	3.91	5.074	8.7	4.82	5.341
2.0	2.72	4.542	5.4	3.94	5.084	8.8	4.85	5.346
2.1	2.76	4.567	5.5	3.97	5.094	8.9	4.87	5.352
2.2	2.80	4.591	5.6	4.00	5.104	9.0	4.90	5.358
2.3	2.85	4.615	5.7	4.03	5.114	9.1	4.92	5.364
2.4	2.89	4.638	5.8	4.06	5.123	9.2	4.94	5.370
2.5	2.93	4.659	5.9	4.09	5.133	9.3	4.97	5.375
2.6	2.97	4.681	6.0	4.12	5.142	9.4	4.99	5.381
2.7	3.02	4.701	6.1	4.15	5.151	9.5	5.01	5.386
2.8	3.06	4.721	6.2	4.18	5.160	9.6	5.03	5.391
2.9	3.09	4.740	6.3	4.20	5.168	9.7	5.06	5.397
3.0	3.13	4.758	6.4	4.23	5.177	9.8	5.08	5.402
3.1	3.17	4.776	6.5	4.26	5.185	9.9	5.10	5.407
3.2	3.21	4.794	6.6	4.29	5.194	10.0	5.13	5.412
3.3	3.25	4.811	6.7	4.31	5.202			
3.4	3.28	4.827	6.8	4.34	5.210			

References

[1] H. Samrani, 2012. ''Mémoire de Master en Energie et Technologie des Matériaux'', Faculté des Sciences de Rabat, 98 pages.

[2] Y. Jannot, 2011. ''Thermique solaire'', Ecole des Mines de Nancy, France, 80 pages.

[3] J.P. Mathieu, 1965. ''Optique électromagnétique'', Société d'Édition d'Enseignement Supérieur S.E.D.E.S., Paris, 341 pages.

[4] A. Nisen, J. Deltour, J. Nijskins and S. Coutisse, 1986. ''Considérations pratiques sur la transmission du rayonnement solaire et de la chaleur pour les matériaux utilisés en serres comme couverture, ombrage et écrans thermiques'', Centre d'Étude des Économies d'Énergie en Cultures Protégées, I.R.S.I.A., Belgique, 94 pages.

[5] Ch. Perrin de Brichambaut, 1963. ''Rayonnement solaire et échanges radiatifs naturels'', Gauthier-Villards, Paris, vol 79, 469 pages.

[6] J. Bahraoui-Buret, M.N. Bargach and M.L. Benkaddour, 1983. ''Le Gisement Solaire Marocain'', Laboratoire d'Energie Solaire et d'Environnement, Rabat – Maroc, 111 pages.

[7] R. Tadili and M.N. Bargach, 2005. ''Une méthode d'estimation du rayonnement solaire global reçu par une surface inclinée. Application aux sites marocains'', Revue de la Société Météorologique de France, 8ème série, n° 50, pp. 46-50.

[8] A. Boussalia, 2010. ''Contribution à l'étude de séchage solaire de produits agricoles locaux'', Mémoire présenté en vue de l'obtention du Diplôme de Magister en Génie Climatique, Alger, 119 pages.

[9] D.K. Gough, 1981. ''Timber seasoning in a solar kiln'', Technical paper, Department of Forestry, Queensland, 0155-9664, no. 24, 6p.

[10] R. Benkhelfellah, S. El Mokretar, R. Miri and M. Belhamel , 2005. ''Séchoirs solaires. Etude comparative de la cinétique de séchage des produits agroalimentaires dans des modèles de type direct et indirect'', 12èmes Journées Internationales de Thermique, Morocco, pp. 259-262.

[11] J.F. Cruz, F. Troude, D. Griffon and J.P. Hébert, 1988. ''Conservation des grains en régions chaudes - 2. ed.'', Techniques rurales en Afrique, Centre d'Études et d'Expérimentation du Machinisme Agricole et Tropical, Ministère de la Coopération et du Développement, FAO, Paris – France, 545 pages.