Effect of Glass Superposition on the Efficiency of the ET 200 Flat Plate Solar Collector

Nabila Ihaddadene, Razika Ihaddadene, and Abdelwahhab Betka
Department of Mechanical Engineering, M'Sila University, Algeria
Email: {MAZ1dz, tassekurt1}@gmail.com, wahaabde@yahoo.com

***Abstract*—This research document presents an experimental study on the effect of the superposition of glass panes on the functioning of a solar thermal collector. Experiments were carried out on an active solar energy demonstration system (*ET 200*). It consists of a flat plate solar collector, water storage tank, a control and command cabinet and a high-power lamp, simulating natural sunlight. Three (*03*) commercial glass panes of 3mm, 5mm and 8mm thick were used. In the first experiment the collector glass was replaced by the superposition of the two panes of 3 and 5mm thick. In the second experiment the collector glass was replaced by the thickest glass (*8mm*). The glass of 8mm thick leaves more energy, generated from the halogen lamp, to penetrate inside the collector than the composed glass (*3mm+5mm*), which leaves less energy reaching the absorber. The glass pane of 8mm thick has an efficiency of about 44% against 40% for the composed glass (*3mm+5mm*). The glass composed from the superposition of the panes of 3mm and 5mm thick exerts a distinct effect, on the solar collector, than the simple glass of 8mm thick. So, it is not possible to replace the single pane of 8mm thick by the superposition of the two panes of 3 and 5mm thick.**

***Index Terms*—solar energy, flat plate collector efficiency, glass superposition, commercial glass**

I. Introduction

The story of renewable energy has experienced a significant acceleration in the wake of the 1973 oil crisis [1], [2]. The natural nuclear reactor which is the sun emits endless energy (3.8×10^{26} W) [3] in all directions. A portion of this clean, free and environmental friendly energy (about 1.7×10^{17}W) [3] is received by the earth.

Solar energy may play an important role to substitute conventional energy sources. Man has always sought to put sunlight in his service. Solar energy can be used in wide applications such as heating, cooling, drying, power generation.., etc.

Flat plate collectors (FPC), a simple design of solar collectors, collect sun radiation and convert it into heat [4]. These devices are widely used for low temperature applications (heating water, space heating…, etc.) [5]. A typical flat plate collector consists of an absorber with integrated or welded tubes in an insulated box covered by transparent sheets (glazing).

In a flat plate collector, solar radiation is used to heat up a flat conductive plate (absorber). The heat is then transferred to a working fluid such as water, flowing in tubes that are attached (or integrated) to the plate. The hot water thus obtained can be used for various purposes.

Several investigations (both theoretical and experimental), on flat plate collectors, have been reported in literature in order to improve their performance [4]-[8].

The aim of the present paper is to investigate the effect of glass superposition on the efficiency of an active solar collector radiated by a halogen lamp. In addition, respond to the following question:

Is it possible to replace a single pane of thickness e by two overlaid glass panes of thickness e_1 and e_2, such that simple glass thickness e equals to the sum of the two thicknesses (i.e. $e = e_1 + e_2$)?

II. Experimental Setup

Experiments done were carried out on a fully-functional demonstration model (ET 200) of a system for heating domestic water using radiation energy from a halogen lamp (see Fig. 1). The important parts of the experimental device used are (see Fig. 1): a flat plate solar collector (1), water storage tank (2), a control and command cabinet (3) and a high-power lamp (4), simulating natural sunlight.

The flat plate solar collector consists of a black flat solar energy absorbing surface, with attached tubes for transferring the absorbed energy to water flowing through them (tubes), a glass cover which reduce convection and radiation losses to the atmosphere, and back and lateral insulation to reduce the conduction losses.

During the experiments, the values of water flow rate, temperatures (at the inlet and outlet of the collector and in the storage tank) and illuminance are read on the digital displays of the control and command cabinet (see Fig. 1).

The composition of the ET 200 solar collector in detail is given in our previous work [6].

Figure 1. Solar water heating system (ET 200).

Manuscript received October 1, 2014; revised June 2, 2015.

doi: 10.18178/ijeee.4.2.151-156

III. Thermal Analysis of a Solar Collector

The basic parameter to consider when studying the performance of solar collectors is the thermal efficiency. It is defined as the ratio of the useful power drawn off via the water heat transfer medium to the irradiance available from the lamp. The thermal efficiency is given by the following formula:

$$\eta = E_u / E. \quad (1)$$

where,

E: Incident solar flux received by the glass surface of the solar collector (W); the irradiance relation is expressed by:

$$E = G \times A_c. \quad (2)$$

where,

G: Incident solar flux by glass surface "illuminance" (W/m^2);

A_c: Area exposed to radiation (m^2).

E_u: Useful flux, i.e. incident solar flux received by water (W). It is given by the following equation:

$$E_u = \dot{m} \times C_p \times (T_2 - T_1). \quad (3)$$

where,

$\dot{m}$: Water mass flow rate (kg/s);

C_p: Water mass specific heat;

T_2: Absorber water outlet temperature;

T_1: Absorber water inlet temperature.

A detailed explanation of the above equations is given in our previous works [6], [8].

IV. Effect of Glass Superposition

To demonstrate the effect of glass superposition on the performance of the ET 200 solar collector, two glass panes of 3mm and 5mm thick were used to replace a glass of 8mm thick. All glasses used have the same characteristics except their thickness; they have also the same dimensions as the apparatus glass. In the first experiment the collector glass was replaced by the superposition of the two panes of 3 and 5mm thick. In the second experiment the collector glass was replaced by the thickest glass (8mm).

To heat well water tank, the collector must be perpendicular to the halogen lamp rays, i.e. the collector must be in a horizontal position [6].

Both tests were performed under the same conditions; collector inclination angle of 0° (horizontal position) and water flow rate maintained at a constant value of 5.9l/h.

Taking measurements of temperatures and illuminance was done every five (05) minutes for a period of 150 minutes (duration of each test). Temperatures measured were: absorber water inlet temperature T_1, absorber water outlet temperature T_2 and tank temperature T_3.

The illuminance measurement was performed by a heliometer placed in the middle of the collector glass under the halogen lamp (see Fig. 1).

All tests were performed in laboratory at a temperature of 18±1 °C.

V. Results and Discussions

For the two experiments performed, the graphs illustrating the evolution of temperatures; at the inlet, at the outlet of the absorber and in the storage tank, as a function of time had the same look.

An illustrative example for the superposed glasses of 3mm and 5mm thick is shown in Fig. 2. During the test duration, all temperatures; T_1, T_2 and T_3, rise with time. As seen in Fig. 2 water temperature at the outlet of the absorber T_2 is greater than water temperature at the inlet of the absorber T_1. Water tank temperature T_3 is found to be between T_1 and T_2. This is due to the heat exchanges taking place in the solar collector, between the absorber plate and water tubes and in the storage tank, between heat exchanger using water as a working fluid and water tank (see Fig. 3). At the beginning of each experiment the working fluid (water) was at the same temperature, i.e. at t = 0, $T_1 = T_2 = T_3$ (see Fig. 2).

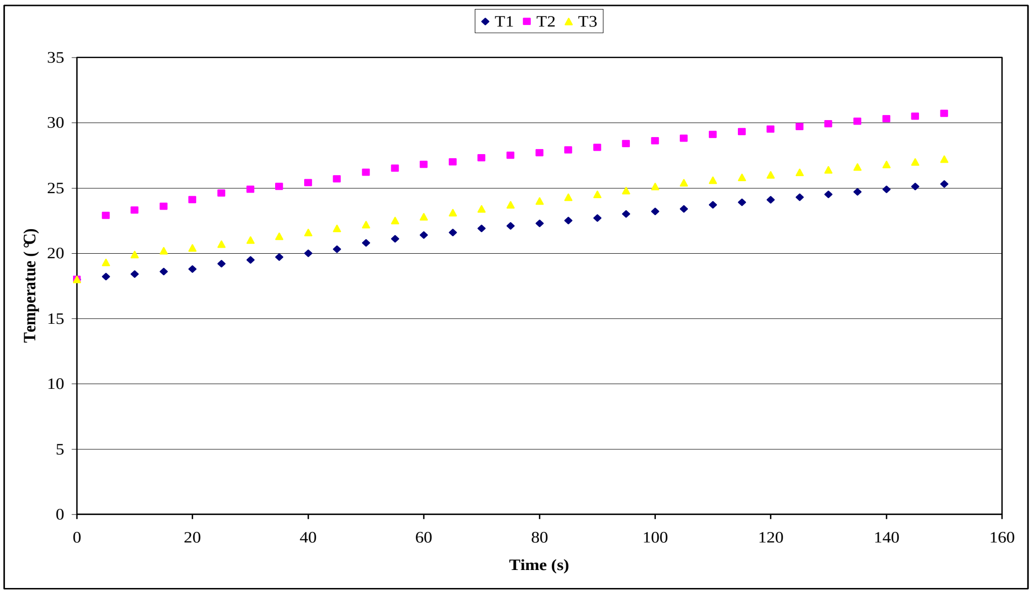

Figure 2. Temperatures T1, T2, and T3 evolution versus time for the superposed panes of 3mm and 5mm.

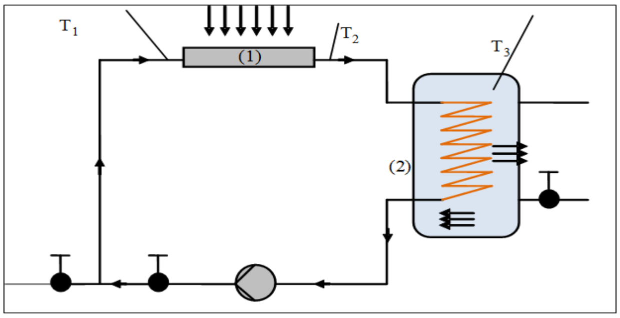

Figure 3. Heat exchanges in the experimental device (1) collector, (2) tank.

Temperature difference at the inlet and outlet of the absorber (T_2-T_1) is influenced by the glass panes tested.

Indeed, during the whole period of the test, temperature difference (T_2-T_1) was markedly greater for the glass of 8mm thick than that resulting from the superposition of the two panes of 3mm and 5mm thick (see Fig. 4).

The composed glass formed by the superposition of the two panes of 3mm and 5mm thick reduced the temperature difference (T_2-T_1) of 8.5% compared to the single pane of 8mm thick. In other words; the glass of 8mm thick leaves more energy, generated from the halogen lamp, to penetrate inside the collector than the composed glass (3mm+5mm), which leaves less energy reaching the absorber. As a first consequence, the incident solar flux received by water flowing in tubes attached to the absorber plate (useful flux), for the single pane of 8mm, is greater than that received in the case of the superposed panes of 3mm and 5mm (see Fig. 5).

So, the composed glass (3mm+5mm) has a higher thermal resistance than the single pane of 8mm thick.

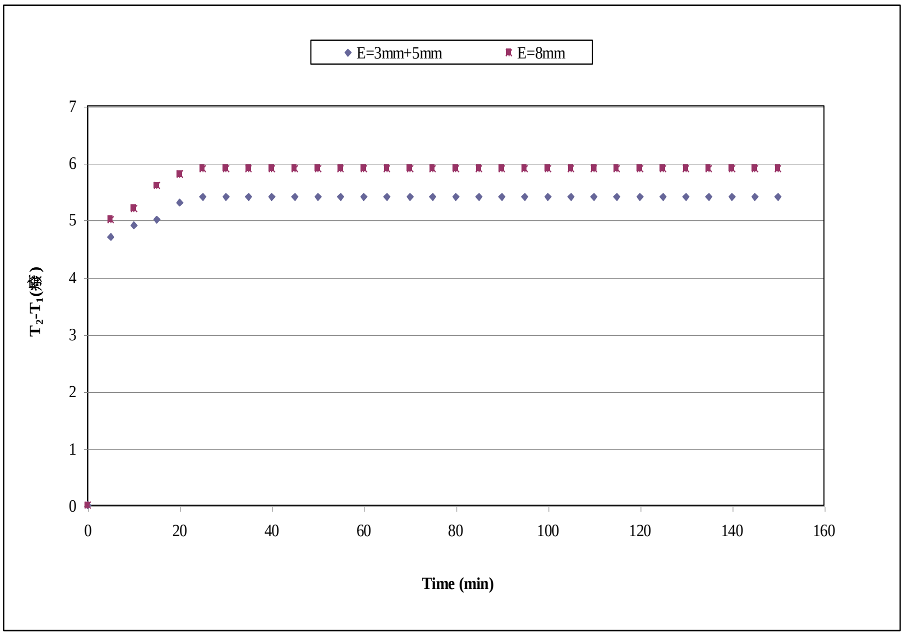

Figure 4. Evolution of the temperature difference (T_2-T_1) versus time for the two panes tested (*3mm+5mm and 8mm*).

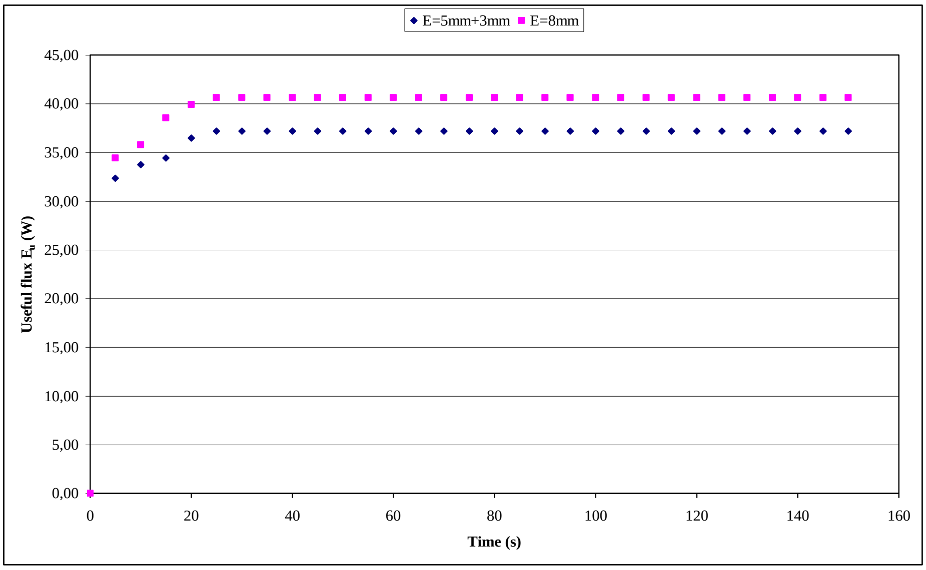

Figure 5. Evolution of useful flux versus time for the two panes tested (*3mm+5mm and 8mm*).

As a second consequence, water tank is well heated when using a single glass pane with a thickness of 8mm than when using a composed glass of the same thickness (3mm+5mm) (see Fig. 6).

Since both tested panes (3mm+5mm and 8mm) have the same thickness, the distance between the collector glass surface and the lamp remains constant. Moreover, the panes tested are similar (same optical and thermal properties), for these reasons the energy received by the glass surface of the collector (illuminance) remains unchanged (constant) during the two experiments (see Fig. 7).

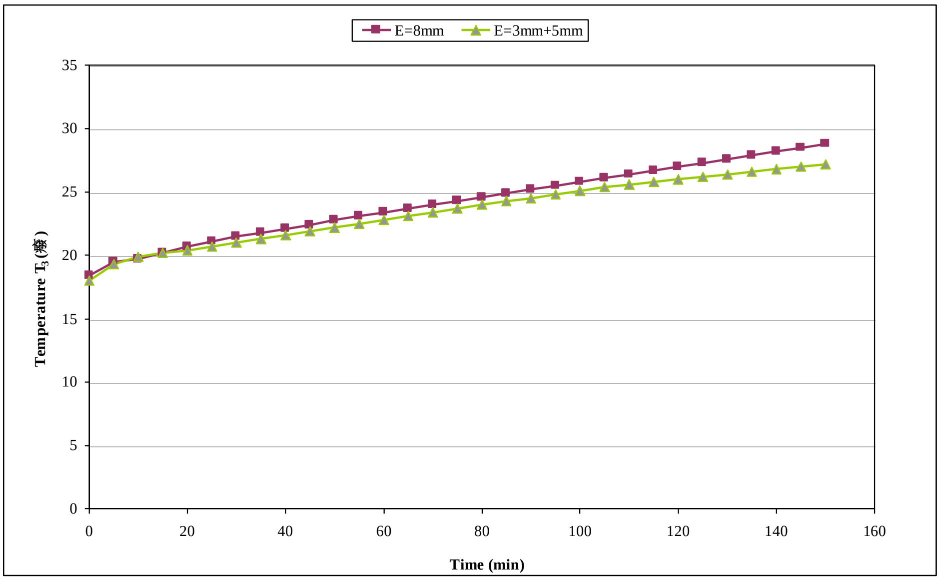

Figure 6. Evolution of tank temperature T_3 versus time for the two panes tested (*3mm+5mm and 8mm*).

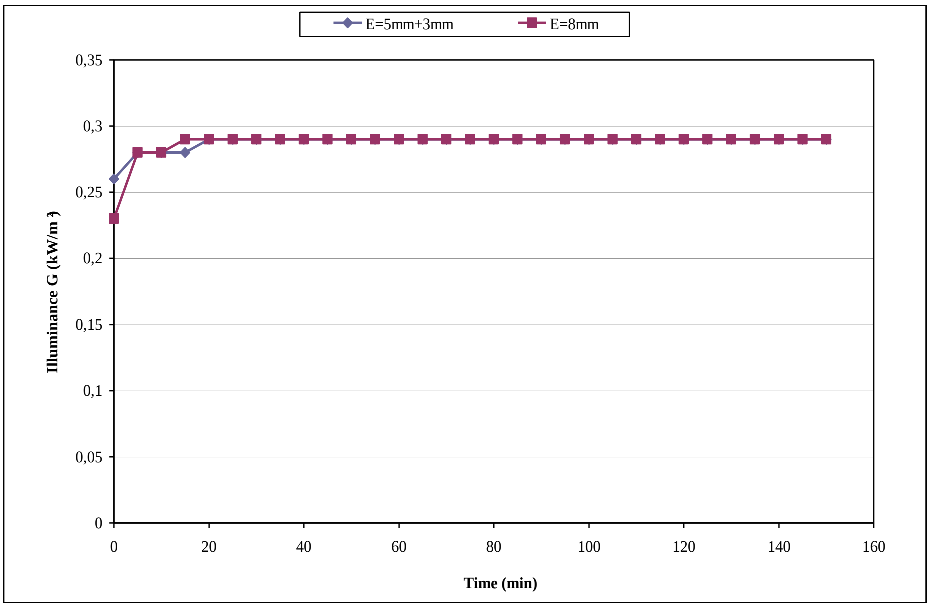

Figure 7. Evolution of the illuminance G over time for the two panes tested (*3mm+5mm and 8mm*).

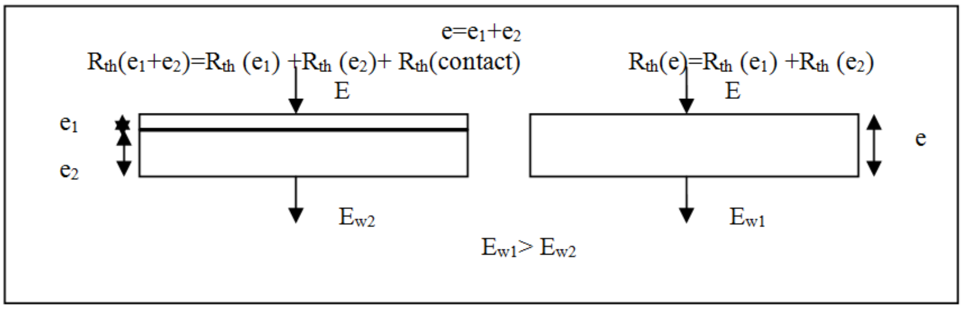

Figure 8. Energy transmission through the glasses tested.

As mentioned previously, the energy transmitted by the glass of 8mm thick was greater than that issued by the composed glass of 3mm+5mm thick (see Fig. 5). Therefore, the composed glass of 3mm and 5mm thick presents a higher thermal resistance than that of the single glass of 8mm thick. Indeed, commercial glasses tested have rough surfaces; air is trapped between the gaps of the superposed glasses forming thus, a stationary air micro layer which is a poor heat conductor (λ_{air}=0.024W/Km). This later acts as an additional thermal resistance, called thermal contact resistance, to the propagation of the energy transmitted to the composed glass (see Fig. 8).

The plot of the evolution of the instantaneous efficiency of the ET200 solar collector versus time for the two panes tested is illustrated in Fig. 9.

As seen, the panes tested (3mm+5mm and 8mm) exert a distinct effect on the performance of the ET200 solar collector. Indeed, the glass pane of 8mm thick has an efficiency of about 44% against 40% for the composed glass of (3mm+5mm) thick. This result is in agreement with the energy carried by water and transmitted to water tank seen previously.

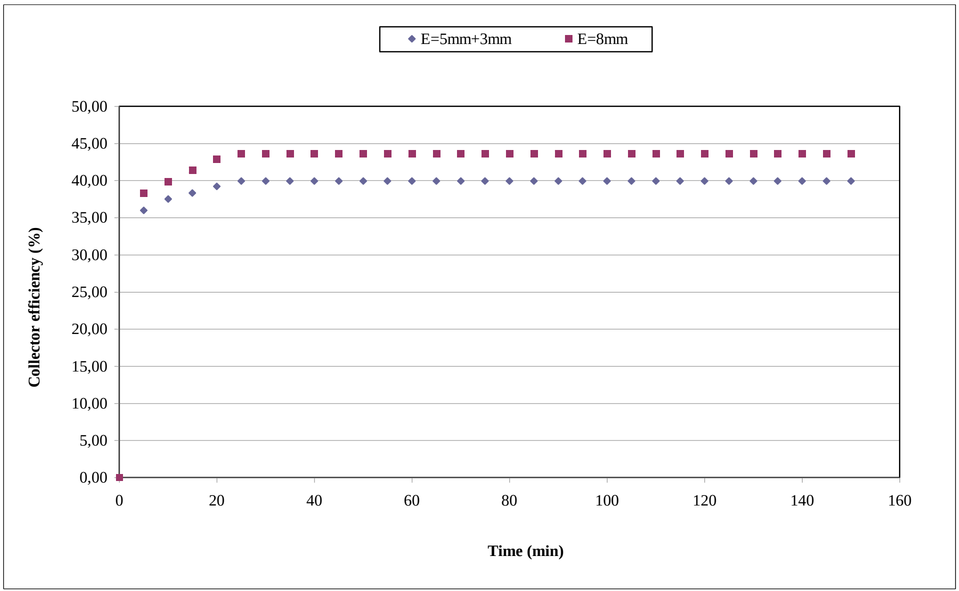

Figure 9. Evolution of the efficiency of the solar collector versus time for the two panes tested (3mm+5mm and 8mm).

The use of a superposition of glass panes (in the open air) instead of a simple glass of the same thickness reduces the performance of the ET200 solar collector of 8.5%.

So the answer to the original question is: It is not possible to replace a single pane of thickness e by two overlaid glass panes of thickness e_1 and e_2, such that simple glass thickness e equals to the sum of the two thicknesses (i.e. $e = e_1 + e_2$), due to the interposition of air micro layer affecting the thermal properties of the composed glass.

VI. Summary

The present experimental study on the effect of the superposition of glass panes on the functioning of the ET200 solar collector allowed us to retain the following:

- The superposition of glass panes (in the open air) does not improve the heat transfer;
- It is inadvisable to use a superposition of glass panes (in the open air) instead of a simple glass of the same thickness to improve the performance of a solar collector;
- It is not possible (in the open air) to replace a single pane of thickness e by two overlaid glass panes of thickness e_1 and e_2, such that simple glass thickness e equals to the sum of the two thicknesses (i.e. $e = e_1 + e_2$).

References

[1] S. A. Kalogirou, “Solar thermal collectors and applications,” *Progress in Energy and Combustion Science*, vol. 30, pp. 231-295, 2004.
[2] M. Selmi, M. J. Al-Khawaja, and A. Marafia, “Validation of CFD simulation for flat plate solar energy collector,” *Renewable Energy*, vol. 33, pp. 383-387, 2008.
[3] Y. A. çengel, *Heat and Mass Transfer*, 3rd ed., McGraw-Hill Companies, 2007, ch. 12, pp. 688.
[4] A. Subiantoro and K. T. Ooi, “Analytical models for the computation and optimization of single and double glazing flat plate solar collectors with normal and small air gap spacing,” *Applied Energy*, vol. 104, pp. 392-399, 2013.
[5] N. G. Mohan and J. P. Agarwal, “A theoretical study of heat transfer in a flat-plate solar collector,” *Solar Energy*, vol. 26, pp. 313-323, 1981.
[6] R. Ihaddadene, N. Ihaddadene, M. Bey, and F. Z. Hamidibacha, “The effects of volumetric flow rate and inclination angle on the performance of a solar thermal collector,” *Energy Conversion and Management*, vol. 78, pp. 931-937, 2014.
[7] R. Tang, Z. Sun, Z. Li, Y Yu, H. Zhong, and C. Xia, “Experimental investigation on thermal performance of flat plate collectors at night,” *Energy Conversion and Management*, vol. 49, pp. 2642-2646, 2008.
[8] N. Ihaddadene, R. Ihaddadene, and A. Mahdi, “Effects of double glazing on the performance of a solar thermal collector,” *Applied Mechanics and Material Journal*, vol. 492, pp. 118-122, 2014.

Nabila Ihaddadene was born in Sidi Aissa W(M'Sila) Algeria on 26th January 1976. She received the PhD Degree in Biomechanics, from Ferhat Abbas University, Sétif (Algeria) in 2009. She received M.S. Degree in Engineering Process from Polytechnic Military School (EMP), Bordj El Bahri, Algiers (Algeria) in 2001. She got the state Engineer degree in mechanical engineering from the University of Msila (Algeria) in 1998. She teaches at M'Sila University from 2001 until now. She works now on renewable energies. She has a lot of publications in the field of renewable energy.

R. Ihaddadene, N. Ihaddadene, M. Bey, and F. Z. Hamidibacha, "The effects of volumetric flow rate and inclination angle on the performance of a solar thermal collector," *Energy Conversion and Management*, vol. 78, pp. 931-937, 2014.

N. Ihaddadene, R. Ihaddadene, and A. Mahdi, "Effects of double glazing on the performance of a Solar thermal collector," *Applied Mechanics and Material Journal*, vol. 492, pp. 118-122, 2014.

Razika Ihaddadene was born in Sidi Aissa W(M'Sila) Algeria on 10th November 1974. She received the PhD Degree in Biomechanics, from Ferhat Abbas University, Sétif (Algeria) in 2014. She received M.S. Degree in Engineering Process from Polytechnic Military School (EMP), Bordj El Bahri, Algiers (Algeria) in 2001. She got the state Engineer degree in mechanical engineering from the University of M'Sila (Algeria) in 1998. She teaches at M'Sila University from 2001 until now. She works now on renewable energies. She has a lot of publications in the field of renewable energy.

R. Ihaddadene, N. Ihaddadene, and M. Merouane, "Comparison of three methods for Weibull distribution in calculating wind energy potential," *Journal of Applied Mechanics and Materials*, vol. 492, pp 574-578, 2014.

N. Ihaddadène, R. Ihaddadène, and A. Mahdi, "Effects of double glazing on the performance of a solar thermal collector," *Journal of Applied Mechanics and Materials*, vol. 492, pp. 118-122, 2014.

R. Ihaddadene, N. Ihaddadene, M. Bey, and F. Z. Hamdibacha, "The effects of light intensity and collector surface on the performance of a solar thermal collector," in *Proc. International Renewable and Sustainable Energy Conference*, 2013, pp. 147-152.

Betka Abdelwahhab was born in M'Sila Algeria on 14th June 1989. He received Master Degree in Mechanics, from M'Sila University, (Algeria) in 2014. He received a Degree in Mechanics, from M'Sila University, (Algeria) in 2012. He received a Degree in Finance, from M'Sila University, (Algeria) in 2012. He got his Baccaloreat Exam in Natural and life Sciences, from Ibrahim Al Tamimi Aghlab High School M'Sila (Algeria) in June 2008. He works in hospital from March 2015 until now.