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Numerical and experimental investigations of heat transfer inside a rectangular channel with a new tilt angle of baffles for solar air heater

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Abstract: This work represents an experimental and numerical study of heat transfer by forced convection inside a channel containing the baffles of a solar collector. The study chose the shape of the baffles as an important factor to improve heat exchange, which has a rectangular shape and is transversal with air flowing at an angle of inclination $\beta = 90$ degrees. The study was conducted at different mass flow rates and different times of the day, to find out the effect of these conditions on the convective heat transfer from the absorber plate to the air through the channel of the collector. The operating conditions taken from the experiment were entered as boundary conditions in CFD, for a comparative study between the heat transfer coefficient by convection of the measurement data, and the simulation data. It was found that the results of it in the numerical and experimental methods gave a good approach, also it can be concluded that this coefficient was affected by different parameters such as the mass flow rate, absorber temperature, and shape of the baffles. Through the results, it was confirmed that when the Reynolds number increases, it means an increase in velocity, which means that the air passing through the duct becomes cooler, therefore there is a difference in temperature between the passing air and the absorber plate, and this leads to an increase in heat transfer between the air and the absorber plate.

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1. Introduction

In the literature, there are many studies to improve thermal collectors, but not all of them are taken into consideration the pressure drop. There are many ways to improve these collectors. Some researchers have changed the shape and length of the channel (Hernández, Quiñonez, & López, 2019; Karim & Hawlader, 2004; Khanlari et al., 2020; Naphon, Kongtragool, & transfer, 2003; Sopian, Daud, Othman, & Yatim, 1999; Yeh & Ho, 2013) and adding baffles with different geometrical shapes (Aoues et al., 2009; Chabane, Moummi, & Brima, 2018; Chamoli & Thakur, 2013; El-Sebaii, Aboul-Enein, Ramadan, Shalaby, & Moharram, 2011; Karim & Hawlader, 2004; Moummi, Youcef-Ali, Moummi, & Desmons, 2004; Ozgen, Esen, & Esen, 2009). In this field, Wijeysundera et al. (Wijeysundera, Ah, & Tjioe, 1982) studied a double pass channel solar air collector and its results were compared with other results of a single pass channel collector in different operating conditions. The study showed that a single-channel thermal transformer has a lower thermal efficiency than a dual-channel, to improve the efficiency of

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the transformer, Akpinar & Koçyiğit (Akpinar & Koçyiğit, 2010) did experimental work on heat transfer through a duct with different shapes of baffles and without (solar air collector with triangular baffles, with leaf baffles and with rectangular baffles). They found the best shape is with leaf baffles where the efficiency has a great value. Experimental work done by Wang et al. (Wang et al., 2020) where study a solar collector with an s-shape of baffles.

The effect of operating conditions on the thermal efficiency of this collector was studied, as well as the effect of the shape of obstacles. Hu et al. (Hu et al., 2019) did an experimental and theoretical study for the new shape of the channel, which is divided into five parts, this operation was done to increase the thermal efficiency of this collector. Through the results, it was found that the greatest values of efficiency were greater than the flat plate collector one at the rate of 16.90%. Also, Khanoknaiyakam et al. (Khanoknaiyakarn, Kwankaomeng, & Promvonge, 2011) did an experimental study of solar air collectors with v-shaped baffles. It was concluded that the addition of baffles increases heat transfer as well as increases the pressure drop. We decided in this study to make a comparison between the experimental side and the simulation side, the novelty in the work is to complete the heat transfer coefficient for this form of baffles in a numerical way after we were calculating it experimentally, and to verify the validity of this digital model to conduct other tests on other baffles in the coming works.

2 Experimental setup

Sunny and clear days were chosen for the experiments and they were carried out at the University of Biskra near the technology hall. The position of the collector was at a fixed angle of inclination β = 38°, and the numerical simulation was done by Ansys workbench fluent software taking into account the experimental boundary conditions to make a comparison.

To improve the heat transfer inside the duct of the collector Fig. 1 (between the absorber plate and the passing air), eighteen baffles were added to the duct with a tilt angle of 90°. The measure was done for three days with an everyday new mass flow rate. The measurement process took place every half an hour from eight in the morning to four in the evening. The measured amounts are the temperature in five points at the level of the absorber plate, outlet, inlet passing air, and pressure drop.

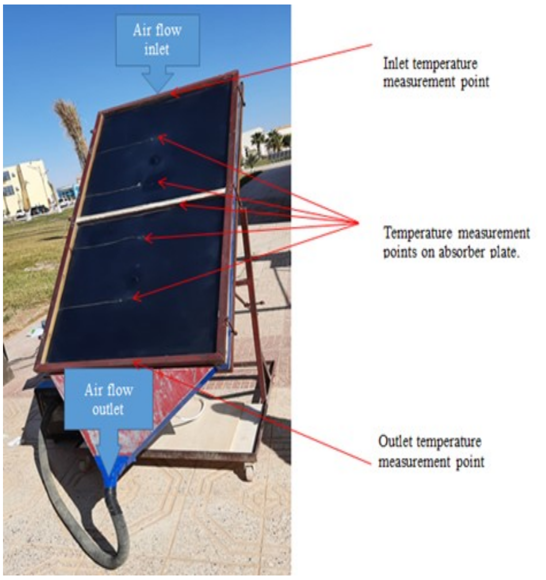

Fig. 1. Experimental setup of the collector.

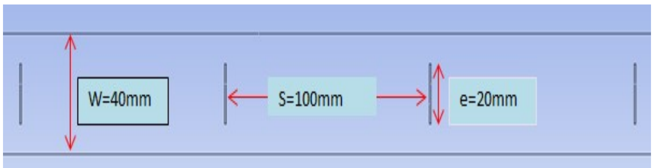

Fig. 2. Dimensions of some elements of the collector.

Fig. 3. The rectangular shape of the baffle.

Dimensions w, s, and e represent the channel width, the distance between two obstacles, and the width of baffles. Fig. 2 represents a cross-section of the air duct and the position of the baffles within it. The shape of a baffle is shown in Fig. 3 and the orientation is shown in Fig. 4.

3 Theoretical study

A theoretical study by Ansys workbench fluent consists of three main points: creating the geometry of our collector with the same dimensions of the experimental case Table 1, meshing the system after that has been put the boundary conditions in the right places from the experimental conditions, and making the solution the following figure (Fig. 4) represents the shape of the collector in the geometrical part.

The next part is meshing the system, the collector has been divided into 417952 nodes which the system going to stabilization Fig. 5 shows the part of meshing of our system.

Table 1

Geometrical properties of the various parts of the collector.

Building elements	Length (m)	Width (m)	Thickness (mm)
Transparent cover	1.94	0.94	3
Absorber	1.94	0.94	0.8
Wood frame	2	1	30×30
Wood sticks	1.94	0.03	30
Insulator	2	1	40
Case	2	1	80
Baffles	0.88	0.02	0.8

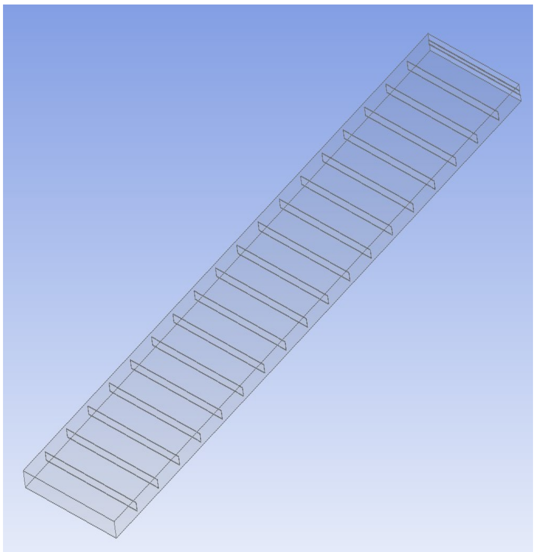

Fig. 4. The shape of our collector.

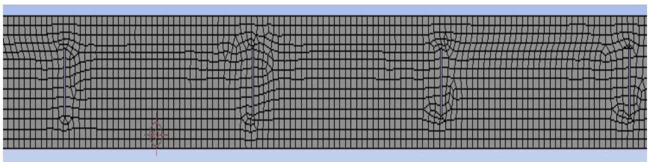

Fig. 5. Domain mesh.

The conditions are the interface symmetry, inlet, outlet, absorber plate, and bottom (as explained in Table 2 and Fig. 6).

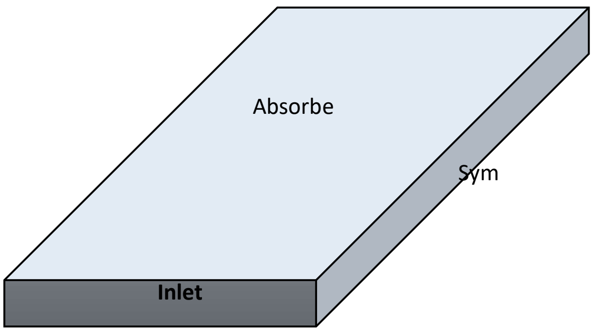

Fig. 6. 3D model of our collector.

Table 2

Boundary conditions.

Absorber plate	constant temperature
Inlet	temperature inlet, mass flow rate
Bottom plate	constant temperature

4 Modeling

In mathematical modeling, there are many relations through which the variation of performance of the studied collector is known, whether from an experimental or a simulation point of view. So the following relationships must be used:

4.1 Relation of heat flux

$$d\Phi = m \times C_p \times dT_f \tag{1}$$

This relation becomes in our study as follows:

$$\Phi = m \times C_p \times (T_{out} - T_{in}) \tag{2}$$

There is also another relation for the heat flux in the case of the forced convection heat transfer. From this relation, the expressions of the heat transfer coefficient become as follows:

$$h = \frac{\Phi}{(T_{abs} - T_{air})} \tag{3}$$

a. Relation of pressure drop

The pressure drop was measured in the experiment in the inlet and outlet through the channel:

$$\Delta p = \Lambda \frac{L}{D_h} \times \rho \times \frac{V^2}{2} \tag{4}$$

Where:

Λ is the coefficient of pressure drop, *L* length of the duct, and D_h is the hydraulic diameter of the collector.

4.3 Reynolds number

A dimensionless number represents the property of velocity in this study. Reynolds number related to inertial forces and viscous forces relation

$$\mathrm{Re} = \frac{\rho \times V \times D_h}{\mu} \tag{5}$$

4.5 hydraulic diameter

The hydraulic diameter depended on the cross-section and section perimeter

$$D_h = \frac{4 \times A}{P} \tag{6}$$

5 Results and discussion

Fig. 7 shows the change in the temperature of the air passing through the collector duct. It was noted that as the mass flow rate increases, the air temperature decreases, where the highest value of air temperature was recorded at the lowest mass flow rate of 0.014 kg/s at time 13:30.

Figs 8, 9, and 10 represent the fields of change in velocity, temperature, and pressure inside the channel, which show the effect of baffles and absorber plate temperature on the heat transfer from the absorber to the air. These fields give a closer picture of the phenomena that occur inside the channel.

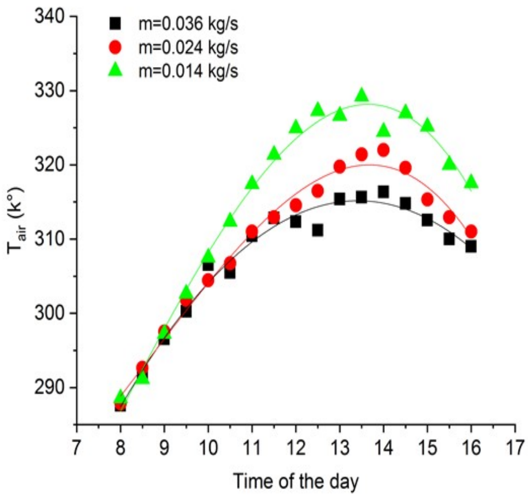

Fig. 7. Variation of average air temperature as a function of time of the day.

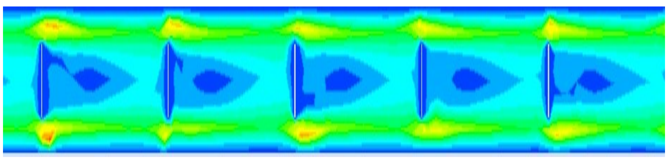

Fig. 8. Velocity contour change field through the baffles inside the channel.

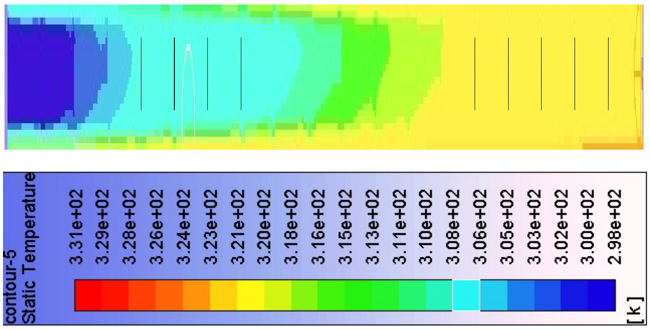

Fig. 9. Temperature field inside the channel.

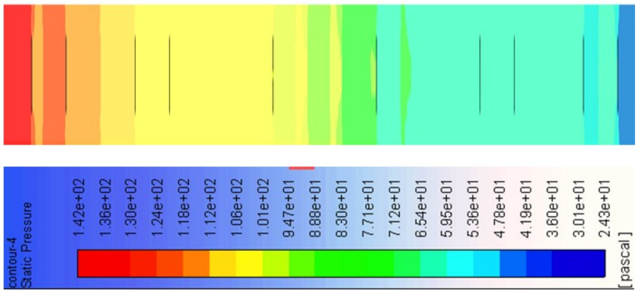

Fig. 10. pressure field inside the channel.

Fig. 11 shows the variation of experimental and theoretical heat exchange coefficient as a function of Reynolds number, the first thing we notice is the convergence of the experimentally measured value with the simulated values of heat transfer coefficient. When the Reynolds number increases, the heat transfer coefficient with convection increases, and this causes an increase in heat transfer between the passing air and the absorber plate. When the Reynolds number increases, it means an increase in velocity, which means that the air passing through the duct becomes cooler, and therefore there is a difference in temperature between the passing air and the absorbent plate, and this results in an increase in the heat transfer between the air and the absorbent plate. Where the highest value of the convective heat transfer coefficient was recorded at the following Reynolds number Re= 1271, its numerical value was h= 27.72 w/m^{2}k, and on the experimental side h= 28.39 w/m^{2}k.

Fig. 12 represents the temperature change of the absorber plate as a function of the time of the day. It was noted that the change of these results has the same trend as the change in air temperature, as the greater the flow, the lower the heat of the absorber plate, due to the increase in the absorption by the air of heat energy, and thus the increase in heat transfer.

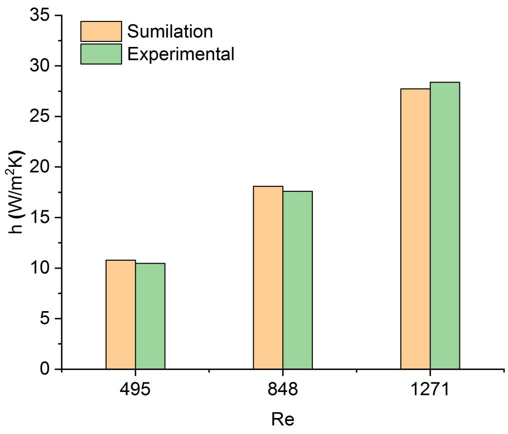

Fig. 11. Variation of experimental and numerical heat transfer coefficient as a function of Reynolds number.

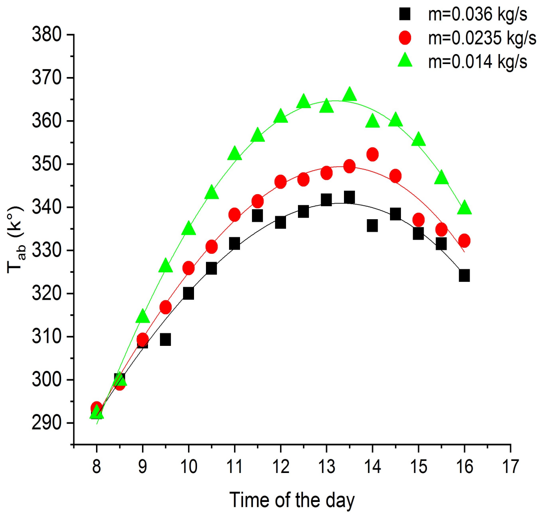

Fig. 12. Variation of average absorber temperature as a function of time of the day.

Fig. 13 represents a comparison between the experimental and simulation results for the pressure drop between the inlet and outlet. Through this figure, the results of the

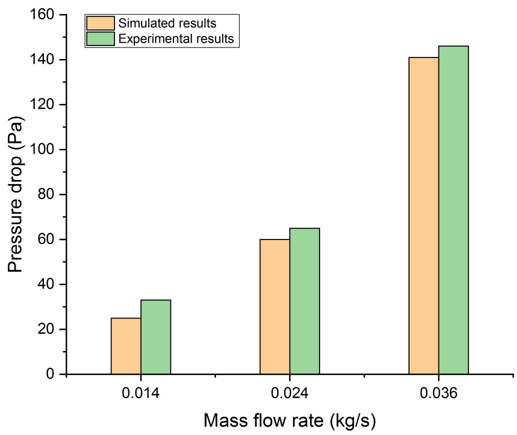

Fig. 13. Variation of the experimental and numerical pressure drop as a function of mass flow rate.

increase, leads to an increase in the pressure drop means the air velocity also increases which effect directly in the comparison were very close, which indicates the validity of the simulation. It was found that when the mass flow rate area of the baffles. This later leads to an increase in the friction coefficient.

Conclusion

This study aims to calculate the heat transfer coefficient by convection inside a rectangular channel with a rectangular baffle, which was perpendicular to the air duct, this study was carried out in two ways, a simulation method and an experimental method. Through this work, the effect of the mass flow rate, and the shape of the baffles on the heat transfer from the absorber plate to the passing air was studied during the hours of the day. The boundary conditions were taken from the experiment to the numerical modeling to make a comparison, according to the experimental conditions, and then the modeling process was done by Ansys workbench fluent software. The results show the following: the experimental results and numerical results are close with no significant difference, corresponding to the coefficient of heat exchange x=2.33%, where the CFD model has been proven correct and can be relied upon in future work by changing the shape of the baffles without the need for costly experimental work to improve these collectors. It was also shown that the increase in the Reynolds number and the addition of baffles increased the value of the heat transfer coefficient, thus leading to an increase in the heat transfer to the air, where the highest value of air outlet temperature of the solar collector was selected at Re= 1271, at the same Re value, the heat transfer coefficient was recorded in the numerical study h= 28.39 W/m²k, parallel with the experimental study h= 27.72 W/m²k. The air and the absorber temperature increase along the length of the thermal collector, which leads to a decrease in the local heat transfer. The same change for pressure drop was observed where the high mass flow rate causes a high-pressure drop.

Nomenclature

Φ	Heat flux	(W)
m	Mass flow rate	(Kg/s)
Cp	Specific heat	(J/Kg K)
T_{abs}	Absorber plate temperature	(k)
T_{air}	Air temperature	(K)
D	haydraulic diameter	(m)
ΔP	pressur drop	(Pa)
Re	reynolds number	
ρ	Fluid density	(Kg/m³)

V	Velocity	(m/s)
µ	kinematic viscosity	(m^2/s)
h	heat transfer coefficient	(W/m^2.k)
W	channel width	(m)
s	distance between two obstacles	(m)
e	width of obstacles	(m)
A	Passage section	(m^2)
P	circumference	(m)

Authorship contributions

Zouhair Aouissi, and Foued Chabane: Conception, writing, modeling, and design of study and acquisition of data and analysis with an interpretation of data.

Mohamed-Salah Teguia, and Djamel Bensahal: Their contribution to the experimental study was to measure different parameters by taking all data on the days studied.

Noureddine Moummi, and Abdelhafid Brima: Drafting the manuscript and revising the manuscript critically for important intellectual content.

Disclosures

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References

Akpinar, E. K., & Koçyiğit, F. (2010). Energy and exergy analysis of a new flat-plate solar air heater having different obstacles on absorber plates. *Applied Energy, 87*(11), 3438-3450. doi:10.1016/j.apenergy.2010.05.017

Aoues, K., Moummi, N., Zellouf, M., Moummi, A., Labed, A., Achouri, E., & Benchabane, A. J. J. o. R. E. (2009). Amélioration des performances thermiques d'un capteur solaire plan à air: Etude expérimentale dans la région de Biskra. *Journal of Renewable Energies*,*12*(2), 237–248-237–248.

Chabane, F., Moummi, N., & Brima, A. (2018). Experimental study of thermal efficiency of a solar air heater with an irregularity element on absorber plate. *International Journal of Heat and Technology, 36*(3), 855-860. doi:10.18280/ijht.360311

Chamoli, S., & Thakur, N. S. (2013). Effect of roughness height ratio in V down perforated baffle roughness on thermohydraulic performance of solar air heater: an experimental study. *International Journal of Ambient Energy, 36*(5), 242-247. doi:10.1080/01430750.2013.853206

El-Sebaii, A. A., Aboul-Enein, S., Ramadan, M. R. I., Shalaby, S. M., & Moharram, B. M. (2011). Investigation of thermal performance of-double pass-flat and v-corrugated plate solar air heaters. *Energy, 36*(2), 1076-1086. doi:10.1016/j.energy.2010.11.042

Hernández, A. L., Quiñonez, J. E., & López, F. H. (2019). Transient numerical study of thermo-energetic performance of solar air heating collectors with metallic porous matrix. *Solar Energy, 178*, 181-192. doi:10.1016/j.solener.2018.12.035

Hu, J., Liu, K., Guo, M., Zhang, G., Chu, Z., & Wang, M. (2019). Performance improvement of baffle-type solar air collector based on first chamber narrowing. *Renewable Energy, 135*, 701-710. doi:10.1016/j.renene.2018.12.049

Karim, M. A., & Hawlader, M. N. A. (2004). Development of solar air collectors for drying applications. *Energy Conversion and Management, 45*(3), 329-344. doi:10.1016/s0196-8904(03)00158-4

Khanlari, A., Güler, H. Ö., Tuncer, A. D., Şirin, C., Bilge, Y. C., Yılmaz, Y., & Güngör, A. (2020). Experimental and numerical study of the effect of integrating plus-shaped perforated baffles to solar air collector in drying application. *Renewable Energy, 145*, 1677-1692. doi:10.1016/j.renene.2019.07.076

Khanoknaiyakarn, C., Kwankaomeng, S., & Promvonge, P. (2011). *Thermal performance enhancement in solar air heater channel with periodically V-shaped baffles.* Paper presented at the 2011 International Conference & Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia (ICUE).

Moummi, N., Youcef-Ali, S., Moummi, A., & Desmons, J. Y. (2004). Energy analysis of a solar air collector with rows of fins. *Renewable Energy, 29*(13), 2053-2064. doi:10.1016/j.renene.2003.11.006

Naphon, P., Kongtragool, B. J. I. c. i. h., & transfer, m. (2003). Theoretical study on heat transfer characteristics and performance of the flat-plate solar air heaters. *International communications in heat and mass transfer*, *30*(8), 1125-1136.

Ozgen, F., Esen, M., & Esen, H. (2009). Experimental investigation of thermal performance of a double-flow solar air heater having aluminium cans. *Renewable Energy, 34*(11), 2391-2398. doi:10.1016/j.renene.2009.03.029

Sopian, K., Daud, W. R. W., Othman, M. Y., & Yatim, B. J. R. e. (1999). Thermal performance of the double-pass solar collector with and without porous media. *Renewable energy*, *18*(4), 557-564.

Wang, D., Liu, J., Liu, Y., Wang, Y., Li, B., & Liu, J. (2020). Evaluation of the performance of an improved solar air heater with "S" shaped ribs with gap. *Solar Energy, 195*, 89-101. doi:10.1016/j.solener.2019.11.034

Wijeysundera, N., Ah, L. L., & Tjioe, L. E. J. S. E. (1982). Thermal performance study of two-pass solar air heaters. *Solar Energy 28*(5), 363-370.

Yeh, H.-M., & Ho, C.-D. J. E. (2013). Collector efficiency in downward-type internal-recycle solar air heaters with attached fins. *Energies*, *6*(10), 5130-5144.