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Optimization of Design Parameters of a Fired Clay Plate Evaporative Heat Exchanger for Air Cooling in Hot and Dry Climates

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ABSTRACT

This study focuses on the optimization of design parameters of an innovative evaporative heat exchanger based on fired clay plates, named "Argiclim," with the aim of maximizing its air cooling performance in hot and dry climates, such as those prevailing in the Sahel region, where temperatures frequently exceed 40 °C with low relative humidity (74 %). By combining rigorous experimental data collected in the field and advanced numerical simulations performed using specialized software such as COMSOL Multiphysics and MATLAB, this research thoroughly investigates the influence of key parameters. These include the spacing between the plates (tested from 2 to 5.5 cm), the air flow velocity through the system (ranging from 0.2 to 4 m/s), as well as the inlet air temperature (35 to 45 °C) and relative humidity, reflecting local climatic conditions. The results reveal an optimal thermal effectiveness of 94 %, achieved with a plate spacing of 2 cm, enabling a significant air temperature reduction of 15 °C (from 44 °C to 29 °C), while the outlet relative humidity reaches 95 %. These performances position Argiclim as a sustainable and environmentally friendly solution to the climatic challenges faced by arid regions. Furthermore, the study provides practical recommendations for adapting the system, particularly by managing the high outlet humidity through devices such as ventilation or desiccation systems. This would broaden its potential applications, ranging from rural housing to public infrastructure, offering a viable alternative to conventional air conditioners in these demanding environments.

Keywords: Evaporative heat exchanger, fired clay, optimization, cooling, hot and dry climate.

1. Introduction

Evaporative heat exchangers based on porous materials, such as fired clay, are emerging as eco-friendly alternatives to conventional air conditioners in countries with hot and dry climates, such as the Sahel region, where temperatures frequently exceed 40 °C and relative humidity remains low (74 %) [1, 2]. These systems exploit evaporative cooling, a natural process in which water, evaporating through a porous surface, absorbs heat from the air, thereby lowering its temperature [3, 4]. This method is low-energy, requires no synthetic refrigerants, is environmentally friendly, and is particularly well-suited to regions with limited access to electricity. This principle, inspired by ancestral techniques such as porous clay pots or wet walls, has been modernized here to meet current needs for thermal comfort in extreme climates [5]. The effectiveness of these exchangers depends on several design parameters. The geometry of the porous elements, such as the thickness and spacing of the clay plates, influences the heat and mass transfer surface area. The airflow rate through the system is also critical: too low a flow limits evaporation, while too high a flow reduces contact time. Finally, the properties of the clay — particularly its porosity (which facilitates water absorption) and its thermal conductivity (which aids heat transfer) — are essential for optimizing performance [6]. This work builds upon the research of Cisse et al. [5], who modeled the hygrothermal transfers in these devices, studying the interactions between sensible heat, latent heat, and water vapor diffusion. The objective of the present study is to optimize the "Argiclim" evaporative exchanger, a prototype designed for cooling in arid regions such as the Sahel. We aim to identify the optimal configurations, such as plate spacing and air velocity, in order to maximize cooling and humidification while achieving high thermal effectiveness, approaching the wet-bulb temperature. To this end, numerical simulations using COMSOL Multiphysics and MATLAB, which model thermal and hydric gradients, were coupled with

experimental validations conducted in Burkina Faso. These real-condition tests help refine the performance of Argiclim, making it viable for local populations.

2. Methodology

2.1 Description of the Exchanger

The Argiclim is a compact system consisting of a PVC tank in which three fired clay plates are arranged vertically and in parallel. A pump distributes water over the top of the plates, which slowly infiltrates through their porous structure, while a variable-speed fan blows hot, dry air through the channels formed between the plates and the tank walls. The evaporation of water in contact with the air causes latent heat transfer, thereby cooling the outlet air. This simple design optimizes the heat exchange surface area while reducing production and maintenance costs, which represents a major advantage for areas with limited access to conventional technologies.

A schematic of the experimental setup used in the study is shown in Figure 1.

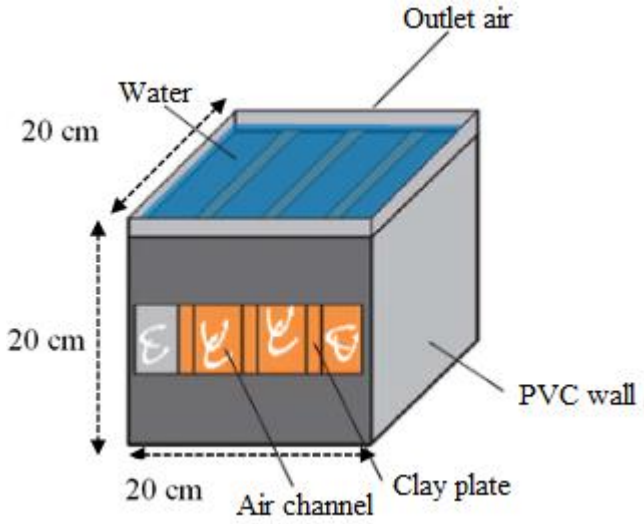


Figure 1 : Schematic of the Argiclim evaporative heat exchanger

The main dimensions of the initial prototype are given in Table 1.

Table 1 : Dimensions of the Argiclim exchanger

Length of Argiclim (cm)	20
Width of Argiclim(cm)	20
Length of clay plates (cm)	18
Width of clay plates (cm)	18
Thickness of clay plates (cm)	2
Spacing between plates (plate-plate) (cm)	2

Distance between plate and PVC wall(cm)	4.1
Number of plates	3
Exchange surface area of one plate (cm^2)	648
Cross-sectional area of air duct (plate-plate) (cm^2)	36
Wetted perimeter of air duct (plate-plate) (cm)	40
Cross-sectional area of air duct (plate-PVC) (cm^2)	73.8
Wetted perimeter of air duct (plate-PVC) (cm)	44.2

2.2. Studied Parameters

To optimize the performance of the "Argiclim" evaporative heat exchanger, three fundamental parameters were studied in detail. The plate spacing was varied from 2 cm to 5.5 cm to evaluate its impact on convective heat transfer and diffusive mass transfer. A reduced spacing increases the specific heat and mass exchange surface area, thereby enhancing the heat flux, but can simultaneously increase pressure drop and airflow resistance, affecting fluid dynamics. The air velocity, tested over a range of 0.2 m/s to 4 m/s, was analyzed to determine its influence on the contact time between the air and the porous plates, a key factor that modifies the evaporation rate and, consequently, the latent heat transfer associated with vaporization. Finally, the inlet air temperature, set between 35 °C and 45 °C to reflect the extreme climatic conditions of Burkina Faso, allowed the assessment of the cooling capacity under realistic scenarios, taking into account thermal gradients and the thermodynamic properties of dry air. These parameters were selected for their direct role in the physical mechanisms of convection, evaporation, and conduction, as well as for their relevance in the design of a practical and efficient system adapted to local constraints.

2.3. Experimental Protocol

The experimental tests were conducted between April and June 2023 in a controlled chamber at the L.E.TRE. A variable-speed fan generated the airflow, while temperature sensors, type-K thermocouples with an accuracy of ±0.5 °C, and hygrometers with an accuracy of ±2 %, measured the conditions at the inlet and outlet. Three configurations were tested: Channel 1 consisting of one plate and one PVC wall, Channel 2 consisting of two plates, and Channel 3 consisting of a single plate. This setup enabled a comparison of performance based on the number of plates and their arrangement.

3. Hygrothermal Transfer Modeling

3.1 Simplifying Assumptions

- Laminar airflow in the channels;
- Constant thermophysical properties;

- Wetted plates without complete saturation;
- Gravity effects are considered negligible;
- One-dimensional transfers in the radial direction.

These assumptions allow the consideration of sensible heat transfer and latent heat transfer resulting from mass transfer by evaporation.

3.2 Transfer Models

- **Sensible Heat**

Sensible heat is the heat transfer between the ambient air and the exchanger. It is given by the following equation [7].

$$d\Phi_s = hdS(T_{am} - T_p) \quad (1)$$

Where: $d\Phi_s$ is the sensible heat flux (energy transfer due to temperature difference), h is the convective heat transfer coefficient, dS is the elementary surface area, T_{am} is the ambient air temperature, and T_p is the surface temperature.

This equation describes the convective heat transfer between the ambient air and a surface as a function of their temperature difference.

- **Mass Transfer and Latent Heat**

The convective mass flux between the saturated vapor at the water–porous plate interface and the ambient air is given by equation (2) [8].

$$d\dot{m} = KdS(C_{v,sat} - C_{v,a}) \quad (2)$$

Assuming that air and water vapor behave as ideal gases, equation (2) becomes (3):

$$d\dot{m} = \frac{KdS}{R_v T_p}(P_{v,sat} - P_{v,a}) \quad (3)$$

The total heat flux required for vaporization through the wall of the wetted clay plates is given by equation (4) [9]:

$$d\Phi_L = L_v d\dot{m} \quad (4)$$

Where: $d\dot{m}$ is the mass flow rate associated with mass transfer (e.g., evaporation), hm h_m hm is the mass transfer coefficient, R_v is the specific gas constant for water vapor (≈ 461.5 J·kg^{-1}·K^{-1}), $P_{v,sat}$ is the saturated vapor pressure at the surface temperature T_p, $P_{v,a}$ is the vapor pressure in the ambient air, and L_v is the latent heat of vaporization, $d\Phi_L$ represents the latent heat flux (energy transfer due to phase change, such as evaporation).

These equations model mass transfer driven by the vapor pressure difference, as well as the associated energy.

- **Total Heat Flux**

The total heat flux is the flux extracted from the water + wall mass through the porous plate walls. It is given by equation (5) [10]:

$$\Phi = hdS(Ta - Tp) - L_v \frac{KdS}{R_v T_p}\left(P_{v,sat} - P_{v,a}\right) \quad (5)$$

The saturated vapor pressure and latent heat of vaporization used in equations (4) and (5) are given respectively by equations (6) and (7).

Latent Heat of Vaporization [11]:

$$L_V = (597 - 0{,}56T_h) \times 4185 \quad (6)$$

Saturated Vapor Pressure [8]:

$$P_{v,sat} = 10^{17.443-\left(\frac{2795}{T_h}\right)-3.868log_{10}T_h} \quad (7)$$

Effectiveness

The effectiveness of the evaporative heat exchanger is defined by equation (8) [12]:

$$\varepsilon = \frac{T_e - T_s}{T_e - T_{wh}} \times 100 \quad (8)$$

Where: T_e is the inlet air temperature, T_s is the outlet air temperature, and T_{wh} is the wet-bulb temperature of the air.

3.3 Numerical Approach

The simulations, based on Luikov's equations, were performed using:

- **COMSOL Multiphysics**: to analyze temperature and humidity gradients.
- **MATLAB**: to evaluate the influence of variable parameters.

3.4 Experimental Validation

Tests were conducted at L.E.T.RE between April and June 2023, measuring temperature and relative humidity along three channels (Channel 1: 1 plate + PVC; Channel 2: 2 plates; Channel 3: 1 plate). The data were used to validate the numerical predictions.

4. Results

4.1 Impact of Plate Spacing

The curves in Figure 2 show the evolution of air temperature for different spacings of the porous plates, with an inlet temperature fixed at 317 K (44 °C), typical of hot and dry climates.

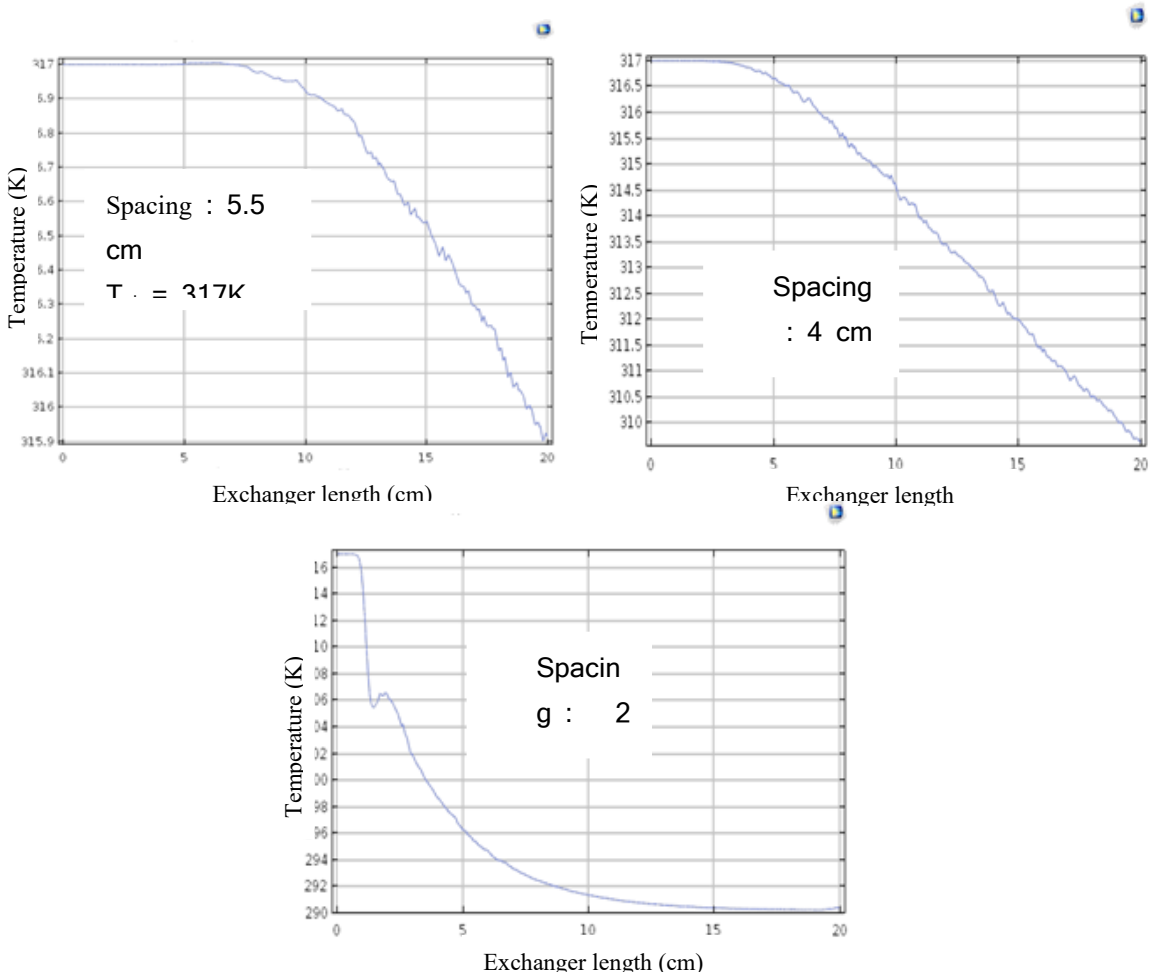


Figure 2: Evolution of air temperature for different spacings of the porous plates

4.2 Influence of Air Velocity

The curves in Figure 3 show the evolution of air temperature as a function of different inlet air velocities through the exchanger. Figure 3 highlights the significant influence of this parameter on system performance. At an air velocity of 2 m/s, the temperature drops by 16 °C (for example, from 45 °C to 29 °C), achieving a thermal effectiveness of 85 %. This optimum results from a balance between convection, which transports heat, and evaporation, which absorbs energy, thereby maximizing heat and mass transfer.

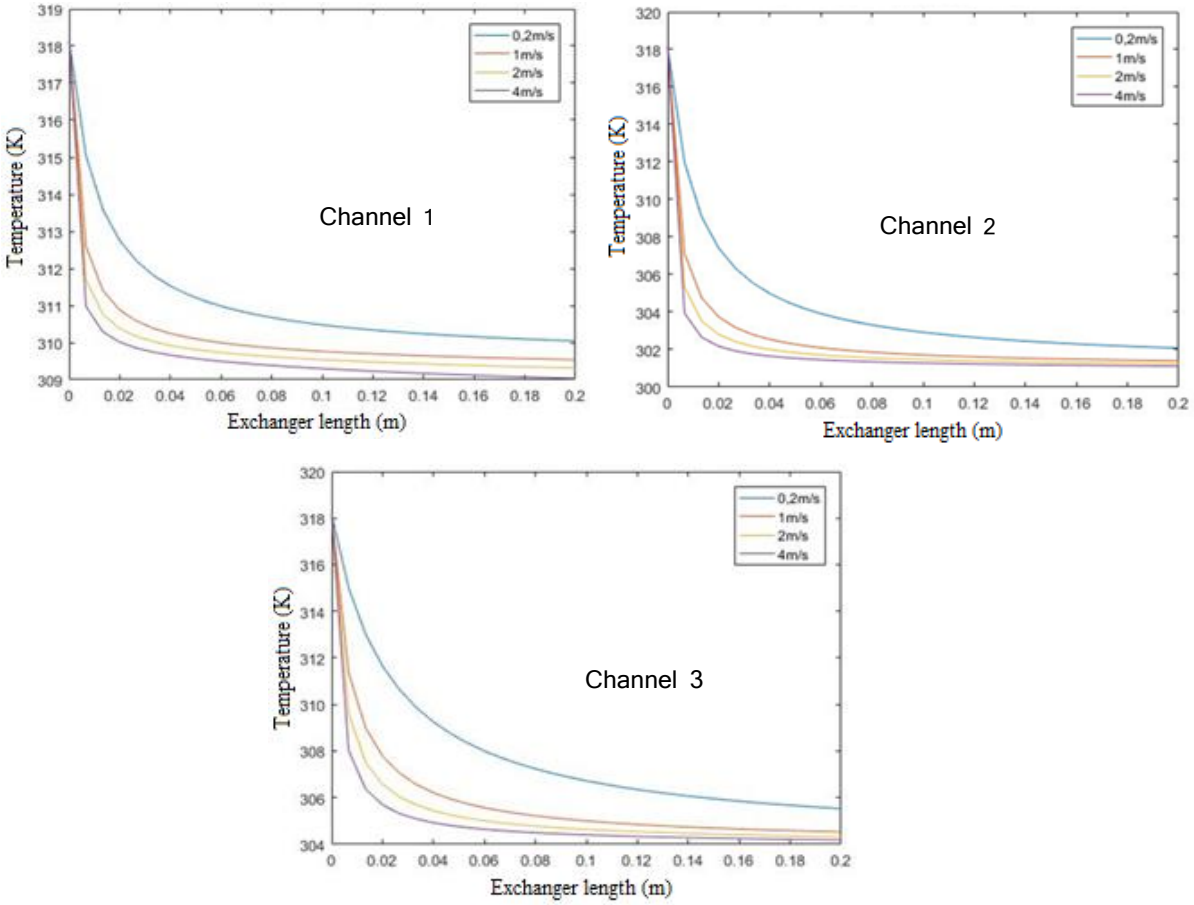


Figure 3 : Evolution of air temperature as a function of different inlet air velocities

In contrast, at 0.2 m/s, the temperature decrease is limited to 8 °C, with effectiveness reduced to 60 %, because the low airflow extends contact time but limits the dynamic interactions required for effective thermal transfer. Figure 4 further supports these findings by showing maximum effectiveness in the range of 1 to 2 m/s, confirming this range as ideal for optimizing the system under real operating conditions.

The curves in Figure 4 show the evolution of the exchanger effectiveness as a function of different inlet air velocities. An air velocity of 2 m/s improves cooling (temperature drop of 16 °C) due to an optimal contact time, whereas at 0.2 m/s, the temperature decrease is limited to 8 °C, reducing effectiveness to 60 %.

An air velocity of 2 m/s improves cooling performance (temperature drop of 16 °C) due to an optimal contact time, whereas at 0.2 m/s, the temperature decrease is limited to 8 °C, reducing effectiveness to 60 %.

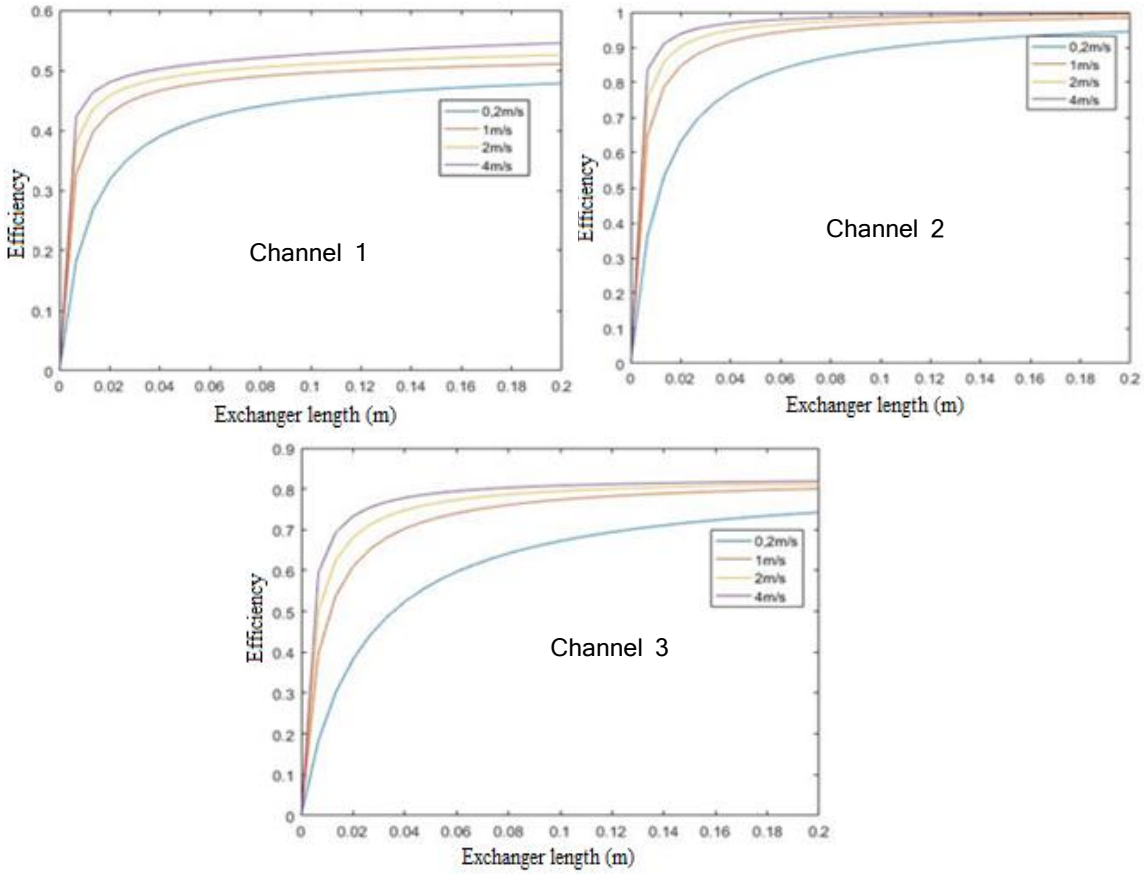


Figure 4 : Evolution of thermal effectiveness in the different channels of the exchanger as a function of inlet air velocity

4.3 Effect of Inlet Temperature

The curves in Figure 5 show the evolution of air temperature along the different channels of the exchanger as a function of inlet air temperature.

For an inlet temperature of 45 °C compared to 35 °C, the effectiveness increases by 10 %, due to more intense evaporation in drier air (initial relative humidity of 30 %).

Figure 5 shows that at inlet temperatures above 38 °C, the air temperature drops sharply at the entrance of the exchanger channels and then varies little, stabilizing toward the outlet. The higher the inlet temperature, the greater the temperature drop: for example, from 45 °C to 31 °C at the outlet, or from 39 °C to 29 °C. This temperature reduction is due to the progressive addition of moisture from the porous plates as the air flows through the channels [1,13].

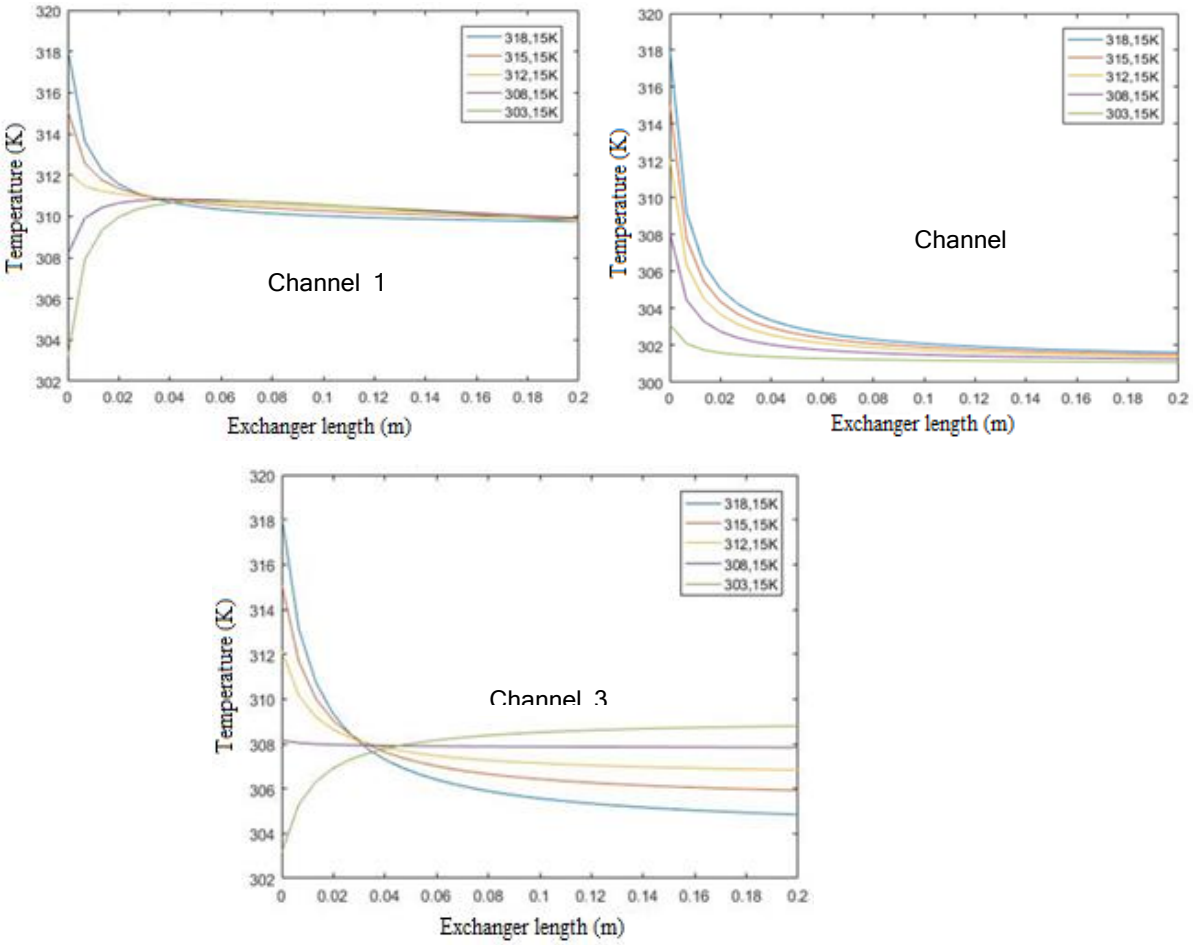


Figure 5 : Evolution of air temperature along the different channels of the exchanger as a function of inlet air temperature

4.4 Humidification

The curves in Figure 6 show the evolution of the absolute humidity of the air along the exchanger.

Figure 6 illustrates that the relative humidity reaches 95 % in Channel 2 (which consists of two plates), compared to 74 % in Channel 1 (consisting of one plate and one PVC wall), based on measurements taken on June 26, 2023. The numerical simulations corroborate these values.

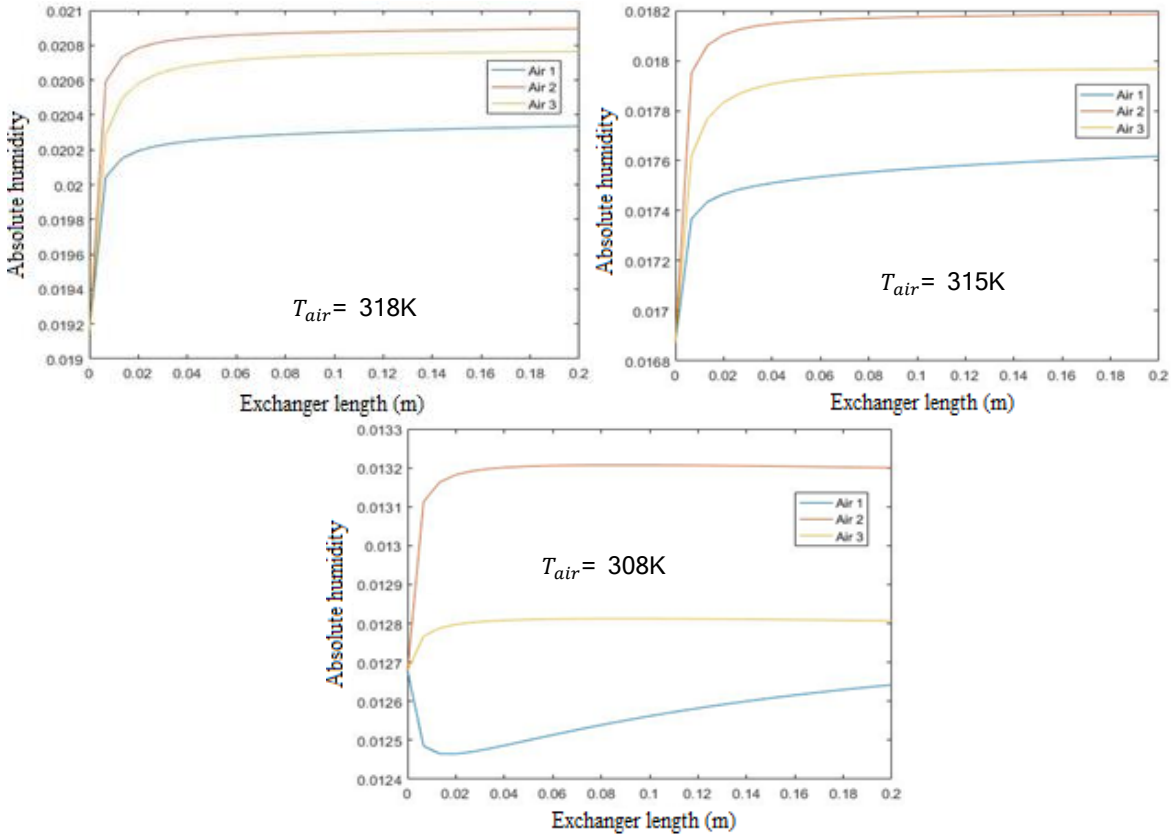


Figure 6: Evolution of absolute air humidity along the exchanger

4.5 Thermal Effectiveness

The curves in Figure 7 illustrate the evolution of the exchanger's thermal effectiveness along the different channels.

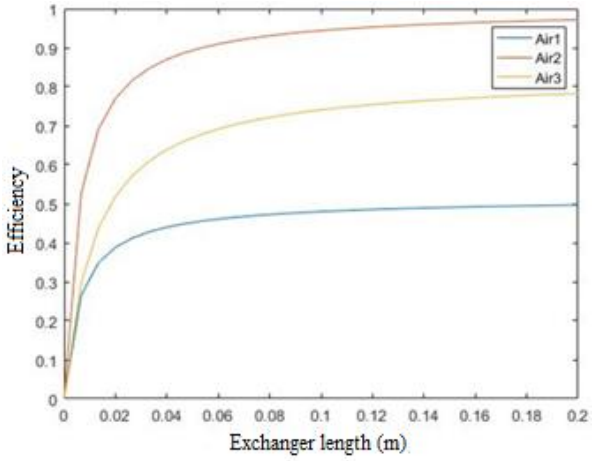


Figure 7: Evolution of thermal effectiveness of the exchanger along the different channels

Figure 7 reveals a maximum thermal effectiveness of 94 %, obtained with a plate spacing of 2 cm, an inlet air velocity of 1 m/s, and an inlet temperature of 45 °C. This result demonstrates successful optimization of the key design parameters.

4.6 Discussion

- **Parameter Optimization**

  A plate spacing of 2 cm maximizes heat and mass transfers. However, a compromise at 2.5 cm could reduce airflow resistance for larger-scale applications. An air velocity between 1 and 2 m/s provides an optimal balance, while higher inlet temperatures enhance evaporation. These results are supported by the theoretical models of [5] and are well adapted to real climatic conditions in Burkina Faso.

- **Validation and Reliability**

  Figure 8 presents the evolution of air temperature along the exchanger, comparing the numerical results from this study with the experimental measurements obtained on June 21, 2023.

  The figure shows very small discrepancies of 2–3 °C between simulations and experiments. These differences are attributed to climatic variations such as wind and ambient humidity.

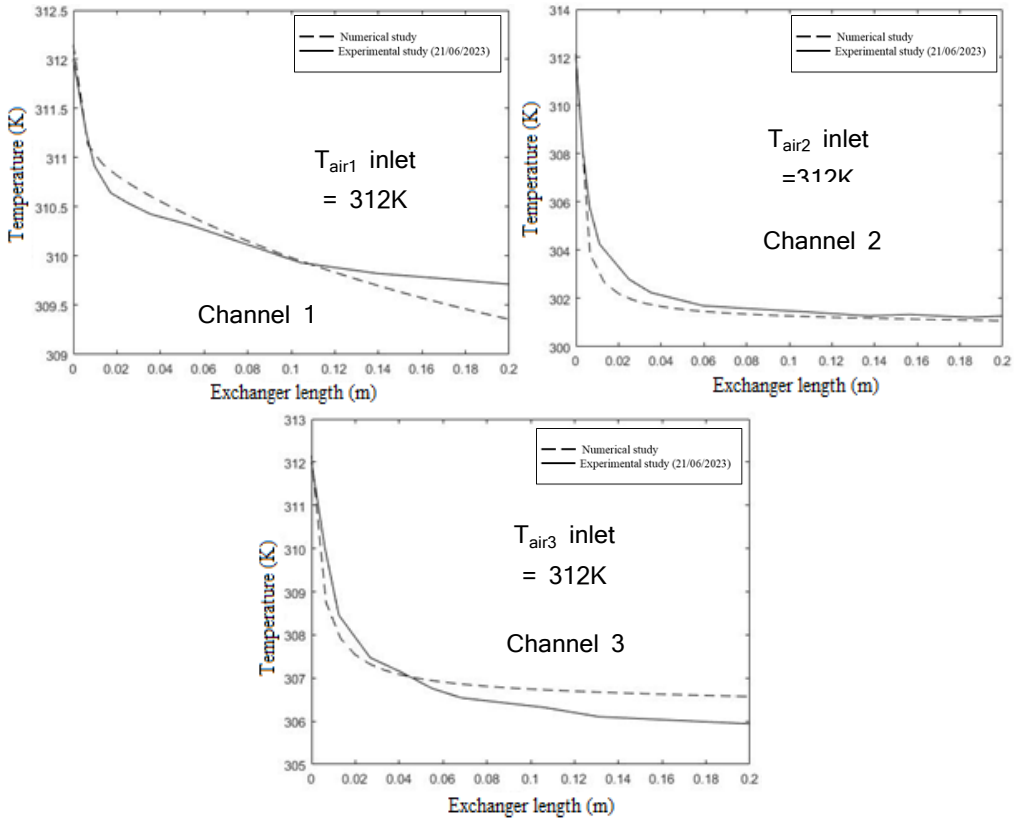


Figure 8: Validation of numerical results (temperature) with experimental measurements of June 21, 2023

Figure 9 presents the evolution of the relative humidity of the air along the exchanger, comparing the numerical results from this study with the experimental measurements obtained on June 21, 2023.

Figure 9 shows minor deviations of 5 % in humidity between simulations and experiments, which are attributed to climatic variations.

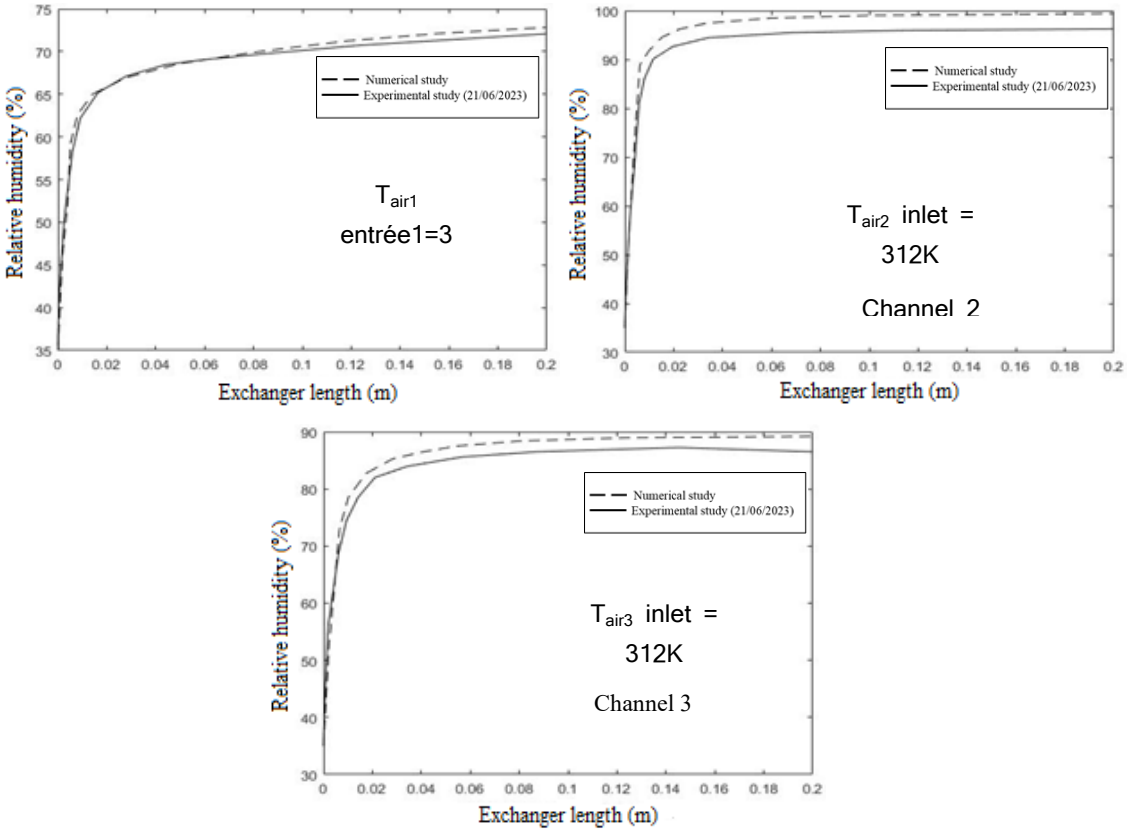


Figure 9: Validation of numerical results (relative humidity) with experimental measurements of June 21, 2023

The discrepancies between simulations and experiments confirm the robustness of the predictions. These minor differences are due to unmodeled climatic variations.

- **Comparison with Other Systems**

  The Argiclim, with a thermal effectiveness of 94 %, outperforms conventional direct evaporative coolers, which typically achieve 60 to 70 % effectiveness, thanks to the porous clay that enhances evaporation. However, M-cycle systems, which offer better humidity control, remain more suitable for humidity-sensitive environments [1, 14].

- **Practical Applications**

  The Argiclim is ideal for hot and dry climates. However, due to its high outlet relative humidity (up to 95 %), it requires ventilation or desiccation systems for indoor spaces [15]. It could be integrated into schools, hospitals, or rural housing in the Sahel region.

5. Conclusion

The optimization of the Argiclim evaporative heat exchanger demonstrates that key design parameters such as a plate spacing of 2 to 3 cm, an air velocity of 1 m/s, and high inlet temperatures up to 45 °C enable a maximum thermal effectiveness of 94 percent, with a temperature reduction of 15 °C (from 44 °C to 29 °C). These results, validated through experimental tests conducted between April and June 2023 at L.E.TRE, confirm the robustness of the numerical simulations performed using COMSOL Multiphysics and MATLAB. They build upon the theoretical and experimental foundations established by Cissé et al., positioning Argiclim as a sustainable and environmentally friendly solution for air cooling in hot and dry climates, particularly in the Sahel region. Nevertheless, the high outlet relative humidity of 95 percent requires further improvements such as the integration of ventilation or desiccation systems to meet the requirements of indoor applications. Future work will include an economic analysis and scale-up studies to optimize the real-world deployment of this system.

References

Cisse, Salifou, Abdoul Aziz Ouiminga, Arnaud Ouermi, Boureima Kabore, Sié Kam, and Dieudonné Joseph Bathiebo. (2025). "Experimental Study of Hygrothermal Exchanges in an Evaporative Heat Exchanger Based on Fired Clay Plates for Air Cooling in Hot and Dry Climates". *Physical Science International Journal* 29 (4):123-32. https://doi.org/10.9734/psij/2025/v29i4894.

Ibrahim, Elfatih & Shao, Li & Riffat, Saffa. (2003). Performance of porous ceramic evaporators for building cooling application. *Energy and Buildings*. 35. 941-949. https://doi.org/10.1016/S0378-7788(03)00019-7.

Watt, J. R. (1963) Evaporative air conditioning. *New York: The Industrial Press*, p. 300.

He, J. and Hoyano, A. (2010) Experimental Study of Cooling Effects of a Passive Evaporative Cooling Wall Constructed of Porous Ceramics with High Water Soaking-Up Ability. *Building and Environment*, 45, 461-472. https://doi.org/10.1016/j.buildenv.2009.07.002

Cisse, S., Kabore, B., Ouedraogo, G. W. P., Kam, S., Bathiebo, D. J. (2024). Numerical Study of an Evaporative Exchanger Based on Fired Clay. *Science Research*, 12(2), 20-27. https://doi.org/10.11648/j.sr.20241202.11

Cisse, S., Zoungrana, W., Nébié, J., Kaboré, B., Komi, N. B., et al. (2026). Modeling of Coupled Heat and Mass Transfer for the Optimization of Evaporative Cooling Using a Porous Clay Plate. *American Journal of Modern Physics*, 15(3), 86-95. https://doi.org/10.11648/j.ajmp.20261503.13

M. DAGUENET, (1985) "Séchoirs Solaires : Théorie et Pratique", *UNESCO, France*.

Mojtabi, Abdelkader & PRAT, Marc & Quintard, Michel & Taine, Jean. (2019). Transferts de chaleur dans les milieux poreux - Conduction, convection, rayonnement. *Physique énergétique*. https://doi.org/10.51257/a-v2-be8250.

Whitaker, S. (1977) Simultaneous Heat Mass and Momentum Transfer in Porous Media: A Theory of Drying. In: *Advances in Heat Transfer*, Academic Press, Vol. 13, 119-203. https://doi.org/10.1016/S0065-2717(08)70223-5

Mojtabi, Abdelkader & PRAT, Marc & Quintard, Michel & Taine, Jean. (2019). Transferts de chaleur dans les milieux poreux - Conduction, convection, rayonnement. *Physique énergétique*. https://doi.org/10.51257/a-v2-be8250

Daguenet, M. (1985) Généralités sur le séchage. In: Daguenet, M., Ed., Les séchoirs solaires: Théorie et pratique, *UNESCO, Paris*, 440-488.

Landis, Jay A., "Numerical Study of a Transpiration Cooled Rocket Nozzle" (1995). *Theses and Dissertations*. 6118. https://scholar.afit.edu/etd/6118

Heidarinejad, G., Bozorgmehr, M., Delfani, S., & Esmaeelian, J. (2009). Experimental investigation of two-stage indirect/direct evaporative cooling system in various climatic conditions. *Building and Environmen*t, 44, 2073–2079. https://doi.org/10.1016/j.buildenv.2009.02.017

Demis Pandelidis, Sergey Anisimov, (2015) Numerical analysis of the heat and mass transfer processes in selected M-Cycle heat exchangers for the dew point evaporative cooling, *Energy Conversion and Management, vol 91* , PP. 63-83.

https://doi.org/10.1016/j.enconman.2014.11.008

Wu, J. M., Huang, X., & Zhang, H. (2009). Theoretical analysis on heat and mass transfer in a direct evaporative cooler. *Applied Thermal Engineering,* 29, 980 984. https://doi.org/10.1016/j.applthermaleng.20 08.05.016