

The effect of the number of fins in a solar-powered seawater distillation apparatus on fresh water production

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Abstract

One way to produce fresh water is by using the principle of solar distillation. However, this method still has very limited freshwater yields. For this reason, it was necessary to study the absorber with varying numbers of fins. A solar distillation apparatus with a total size of 110.5 cm x 80 cm, a front height of 21 cm and a rear height of 52.5 cm had been tested with absorbers that was varied in the numbers of fins, namely without fins, 10 fins, and 15 fins. The seawater level above the absorber was kept constant and the same for all three distillers. The test results show that the absorber without fins produces 1.18 kg of freshwater per day, the one with 10 fins produces 1.24 kg and the one with 15 fins produces 1.38 kg. Therefore, based on the results of the largest freshwater mass, the distiller with 15 fins is the best.

Keywords: Absorber; Distiller; Freshwater mass; Number of fins; Seawater

1. Introduction

Water is a crucial necessity for the survival of living things, especially humans. This is because humans require water not only for bodily needs but also for various other needs such as washing, cooking, and so on. Water is abundant in nature, with approximately 70% of the Earth's surface covered by water as explained by Tennant [1]. Indonesia is a country made up of various islands, each with its own unique potential, so it's no surprise that Indonesia has a long coastline. However, not all regions have adequate water resources. Humans often face difficult challenges when freshwater resources are limited and demand increases.

Akhirudin [2] stated that drinking water crises are generally experienced by most coastal communities, especially those on remote islands. Several large areas along the southern coast of Java, West Nusa Tenggara, and East Nusa Tenggara frequently experience difficulties in providing clean water. The clean water shortages affecting eastern communities are not new; they have become a tradition every dry season.

There are several methods often used to obtain clean water, namely boiling, filtering, distillation, and others. Boiling is only done to kill germs and harmful bacteria, but impurities in the form of small solids cannot be separated from the water. Filtration is used only to filter impurities in the form of small solids, but harmful germs and bacteria cannot be separated from the water. Distillation is an effective method used to produce clean water free from germs, bacteria, and impurities.

Seawater distillation has been practiced for many years. Water distillation technology to obtain clean water from dirty or seawater essentially involves evaporating seawater by heating it, then condensing the vapor to produce clean water. The heat sources used come from a variety of energy sources, including oil, gas, electricity, solar energy, and others as reported by Abdullah [3].

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La Aba [4] conducted a study by testing the effect of absorber surface shapes made of zinc (flat, wavy, and serrated) on temperature increases in the solar still and the total volume of distilled water. The results showed that the seawater temperature in the solar still was higher for absorbers with wavy surfaces, followed by serrated surfaces, and flat surfaces. This occurs because wavy surfaces have a larger surface area because more solar radiation is absorbed by the absorber, so the temperature is also higher. The increase in temperature causes the amount of seawater to evaporate, so the water vapor pressure becomes quickly saturated and finally condensation occurs. Thus, it can be said that the higher the temperature, the faster the evaporation of seawater, and the greater the volume of distilled water from the distillation.

Solar distillers are made with water reservoirs as a place to pour the water to be distilled. These reservoirs are connected by connecting pipes and arranged in such a way that they are connected and under each other, forming a 30° angle of inclination. This allows water to flow from the upper reservoir to the lower one due to the force of gravity. At the top, the reservoir arrangement is covered with a transparent cover (glass, mica, acrylic, plastic). This allows sunlight to enter and heat the water, causing it to evaporate. The resulting water vapor rises upwards, and due to being blocked by the lower/inner surface of the cover, which has a lower temperature, results in the water vapor condensing to form water droplets (condensate). Because the cover is installed at an angle, the condensate droplets flow along the cover and fall at the end to be collected [5]. (Bilad, 2009)

Yani [6] conducted an experimental study comparing a 35° angle cover and a roof-shaped cover with the same reservoir area. The results showed that the 35° angle cover produced higher condensate water productivity compared to the roof-shaped cover due to its larger surface area, resulting in more water vapor adhering to the lower surface of the cover. Meanwhile, the efficiency of the solar still using the 35° angle cover was higher than that of the roof-shaped cover.

One of the main modifications made to improve the efficiency of solar distillation is the attachment of fins to the surface of the heat absorber plate. Fins are a type of surface that is expanded to increase the given surface area, the rate of heat flow from the heat absorber plate surface to the brine, and control the heat flow within the basin. This serves to provide solar power with better heat flow at higher levels, increasing the rate of seawater evaporation and therefore increasing efficiency, Mohan et al. [7], Istanto and Juwana [8].

In the solar powered seawater distillation system, the absorber plate plays a very important role because it functions as an absorber of solar radiation intensity and converts it into heat energy. Based on the results of the 3-day experiment, fresh water was produced for the first day with a flat absorber of 0.836 kg, a fibrous absorber of 0.825 kg, a finned absorber of 0.944 kg, then for the second day with a flat absorber of 0.940 kg, a fibrous absorber of 0.879 kg, a finned absorber of 0.991 kg, and for the third day with a flat absorber of 0.927 kg, a fibrous absorber of 0.902 kg, a finned absorber of 1.091 kg. so it can be concluded that the finned absorber produces more maximum fresh water (Faisal [9]). In Faisal's [9] study, distillation using finned absorbers produced more freshwater, therefore, finned absorbers require further research. Therefore, this study examined the effect of the number of fins on freshwater production.

2. Material and methods

2.1. Experimental facilities

The method used in this research was an experimental method, which involves creating a test instrument and then conducting tests. This research was conducted in several stages or processes, starting with calibrating the instrument and ending with data collection. This method encompassed all activities that were carried out to solve the problem or conduct the analysis process for the thesis.

The devices used in this experiment were a hammer, a wood saw, thermocouples, a pyranometer, a cutter, a scissors, a screwdriver, a scale, an anemometer, a meter roll, and nails. The materials used to make this research include the following things; plywood, clear glass, wood glue, sea water, hose, duct tape, plastic bucket, black paint, and calsiboard. The schematic diagram of the apparatus can be seen in figure 1, consisting of two circle buckets (one for the water source and one for placing the float), three identical distiller with different absorbers, and three bottles to hold freshwater.

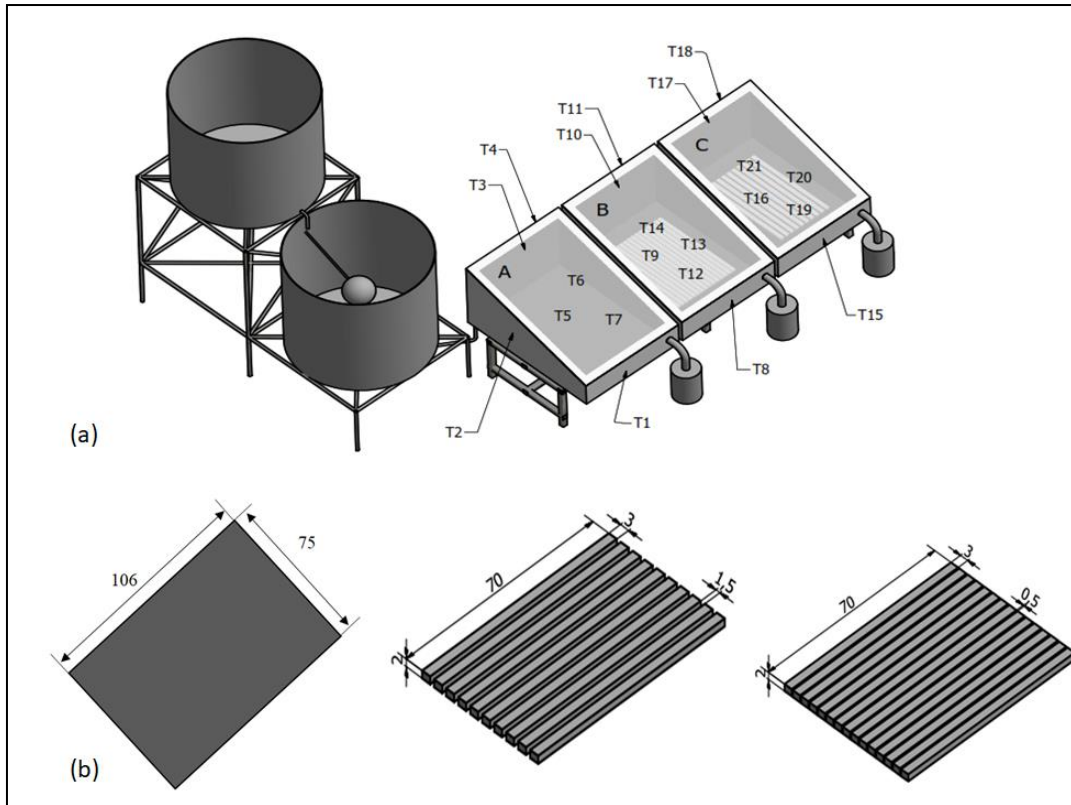


Figure 1 The experimental apparatus (a) three dimensional view of distillers with thermocouple points, (b) the shapes of absorbers

All temperatures were recorded using K type thermocouples connected to a data logger. The water flowed from the upper circular bucket to the lower circular bucket where the float was installed. When the water level inside the distiller went down due to evaporation, then the float open the valve and the salty water come into the distillers. This process occurred continuously until the water in the upper circular bucket empty. The vapour touched the distiller cover became dew that flowed down along the glass cover and collected in a bottle.

The equation for the rate of conduction is known as Fourier's Law of Heat Conduction, which is mathematically expressed as follows:

$$Q_k = kA\Delta T / d \quad (1)$$

Q_k is the conduction heat transfer (W), k is the thermal conductivity ($\text{W/m}^2\text{°C}$), and A is the cross sectional area perpendicular to the direction of heat flow (m^2), and ΔT is the temperature change (°C), while d is the material wall thickness (m). Table 1 describes the thermal conductivity of the material used in this study.

Table 1 Thermal conductivity of the material

No.	Material	Thermal conductivity (W/m°C)
1.	Glass	0.8
2.	Calsiboard	0.048
3.	Styrofoam	0.033

Based on the fluid flow, convection heat transfer can be classified as:

- Forced convection, which occurs when the fluid flow is driven by an external force, such as a blower, pump, or fan.

- Natural convection, which occurs when the fluid flow is driven by the buoyancy effect. In fluids, temperature is inversely proportional to density.

The basic equation for the concept of convection heat transfer is Newton's law. Newton's law states:

$$Q_c = h_c A (T_w - T_s) \quad (2)$$

Q_c is convection heat transfer rate (W), h_c is convection heat transfer coefficient (W/m²K), A is the heat transfer surface area (m²), T_w and T_s are wall and ambient temperatures (°C).

The amount of energy obtained from solar radiation is the multiplication of the received radiation intensity by the surface area, using the equation:

$$Q_r = \sigma A T^4 \quad (3)$$

Q_r is the heat transfer rate due to radiation (W), A is the surface area of radiation (m²), T is temperature (K) and σ is the proportionality constant, also known as the Stefan-Boltzmann constant, with a value of 5.67×10^{-8} W/m²K⁴. It should be noted that this equation only applies to thermal radiation, Holman [10]. In this case, all analyses of temperature in radiant heat exchange are in absolute Kelvin (K).

The efficiency of the distillation apparatus is used to determine the ability of the distillation apparatus to produce fresh water from the intensity of sunlight received. The efficiency of a solar distillation apparatus is determined using the following equation, Mulyanef [11].

$$\eta = \frac{Q_u}{Q_i} \quad (4)$$

η is the efficiency, Q_u is the useful heat transfer rate (W) and Q_i is the heat transfer rate coming into the distiller (W). To determine the heat entering the distillation apparatus, the useful heat generated, and the heat lost, the following equation can be used, Suradi et al. [12], Astawa and Suciption [13]. The heat received by the distillation apparatus is heat transferred by radiation from the sun's heat to the absorber plate. To determine the extent of heat transfer, the following formula can be used:

$$Q_i = \tau A I \quad (5)$$

I is solar intensity (W/m²), A is the glass cover area (m²), τ is the cover transmittance. The latent heat of vaporization in a distillation apparatus is the heat used to evaporate seawater into fresh water. This heat can be calculated using the formula:

$$Q_{ul} = m h_{fg} / t \quad (6)$$

m is the mass of condensed water (kg), h_{fg} is the enthalpy of evaporation (J/kg), Q_{ul} is the latent heat (W). Sensible heat is the heat that causes an increase/decrease in temperature. Sensible heat can be calculated using the formula:

$$Q_{us} = m c_p \Delta T / t \quad (7)$$

Q_{us} is the sensible heat (W), then the total useful heat is

$$Q_u = Q_{ul} + Q_{us} \quad (8)$$

t is the experimental time (s), and Q_o is the heat loss that can be predicted using an equation below

$$Q_o = Q_i - Q_u \quad (9)$$

3. Results and discussion

To facilitate analysis, the test data is presented in graphical form. In this study, the collected data are presented and described. Mass of fresh water produced is presented in figure 2.

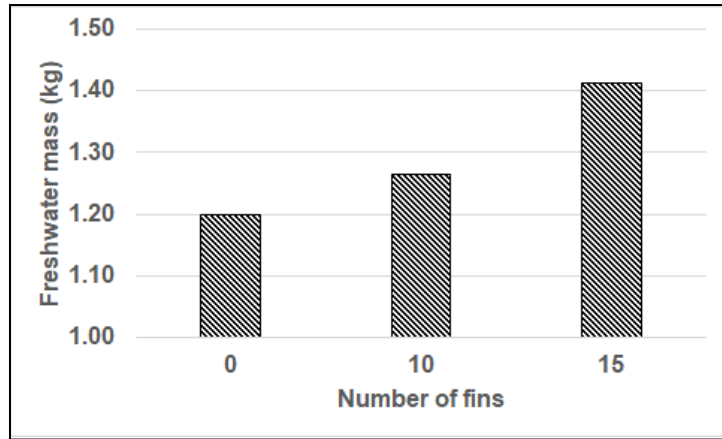


Figure 2 Freshwater production versus number of fins

Figure 2 illustrates that the highest freshwater mass is obtained using absorber with fins of 15. There is a clear trend showing that as the number of fins increases, the freshwater mass also increases. Specifically, the mass increases from 1.20 kg at 0 fins, to 1.30 kg at 10 fins, and to 1.40 kg at 15 fins. This suggests that the number of fins might have a positive correlation with the freshwater mass. However, based on general scientific understanding, such a trend might suggest that the fins contribute to a larger surface area or more complex structure, which could lead to greater retention or accumulation of freshwater mass.

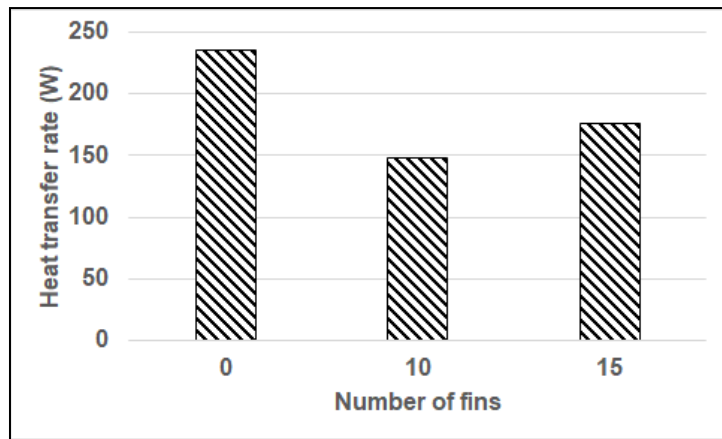


Figure 3 Heat transfer rate versus number of fins

The data suggests that as the number of fins increases, the heat transfer rate decreases. This could be due to a number of factors: Fins are typically used to increase surface area for heat exchange, so increasing the number of fins may initially seem like it would enhance heat transfer. However, there could be diminishing returns after a certain number of fins. Adding more fins may lead to a situation where the fins interfere with one another, or there is less effective water flow or thermal contact, which could reduce the heat transfer rate. Another possibility is that with more fins, the system might reach a point of thermal equilibrium where increasing the surface area doesn't increase heat transfer but might create thermal resistance due to over complication of the system. In figure 2, it is shown that as the number of fins increased, the freshwater mass increased. This might suggest that the fins played a role in increasing the mass retention. However, in figure 3, the heat transfer rate decreases with more fins, which suggests that fins might have a complex or trade-off effect on the system. More fins increase freshwater mass but reduce the ability to transfer heat efficiently. This indicates that while fins can enhance mass retention or storage (as shown in figure 2), their impact on heat transfer may not always be linear or beneficial beyond a certain point.

There is a positive correlation between the number of fins and freshwater mass. As the number of fins increases, the freshwater mass also increases. This suggests that the fins may have helped in capturing or retaining more water, possibly due to a larger surface area for water to accumulate or interact with the environment. In figure 3, there is a negative correlation between the number of fins and the heat transfer rate. As the number of fins increases, the heat transfer rate decreases. This is surprising, because in many systems (like heat exchangers), fins are usually added to

enhance heat transfer by increasing the surface area. However, here, more fins seem to interfere with efficient heat dissipation. There are a few possible reasons for this seeming discrepancy: Adding more fins likely increases the surface area, and if the fins are structured in a way that encourages the water to cling to them (such as in a surface tension or capillary effect), it could result in a greater amount of water being retained, hence the increase in freshwater mass. In the case of heat transfer, additional fins increase surface area, but after a certain point, they could obstruct airflow or limit the efficiency of heat dissipation. If the fins are packed too closely, they may not allow for proper airflow, which is necessary for cooling. Furthermore, the increased surface area could lead to thermal resistance if the fins aren't perfectly designed to conduct heat away efficiently.

When fins are added, there may be a reduction in thermal conductivity if the fins aren't well-integrated or if the material of the fins isn't optimal for heat transfer. Instead of increasing the heat transfer rate, the fins may end up creating a thermal barrier. This could explain why the heat transfer rate decreases as the number of fins increases. Moreover, overcrowding of fins might lead to a situation where the heat transfer is hindered by interference between them, causing them to act less effectively as heat dissipaters.

In systems involving fluid dynamics (e.g., airflow over fins), the effectiveness of the fins is not just about surface area but also about how air or water flows around them. With an increasing number of fins, you might have turbulent flow or interference that reduces the efficiency of heat transfer, as the heat isn't carried away as efficiently as it might be in a system with fewer fins. In the case of freshwater mass, the fins may be capturing or slowing down water without worrying about airflow interference, thus leading to an increase in the amount of mass that can be retained.

The material and shape of the fins play a huge role in both heat transfer and mass retention. If the fins are designed primarily for one function (e.g., mass retention), they may not be optimized for another (e.g., heat transfer). A well-designed fin system for heat transfer would use materials with high thermal conductivity (like copper or aluminum), while fins designed for water retention might use different materials or shapes to maximize surface contact with water, which could lead to conflicting results between the two graphs.

There might be an optimal number of fins beyond which the benefits of increasing surface area for both heat transfer and freshwater mass retention are reduced. For freshwater retention, more fins can increase the total surface area to capture water, while for heat transfer; too many fins might impede effective heat dissipation.

The purpose of the fins might differ in the two experiments. In the first experiment, the fins could be acting as surface structures to accumulate freshwater (e.g., through surface tension, capillary action, or condensation), whereas in the second experiment, the fins are more likely acting as a surface to dissipate heat. The need for thermal efficiency could conflict with the goal of maximizing mass retention.

It's possible that the material or design of the fins is limiting the heat transfer in the second graph. For example, if the fins are made of a material that is better at holding water than dissipating heat, this could explain the opposing trends observed between the two experiments. Were other factors such as temperature, material properties, or environmental conditions held constant between the two experiments? Any variations could lead to differences in the results. The size, shape, and spacing of the fins in both graphs could be playing a significant role in these divergent results. How were the fins designed or arranged? Were the methods for measuring freshwater mass and heat transfer rate similar in their precision and accuracy? Differences in measurement techniques could lead to apparent discrepancies in the data.

While the number of fins increases freshwater mass (Graph 1), it seems to reduce heat transfer (Graph 2). This suggests a trade-off in the system between maximizing mass retention and efficient heat dissipation. The specific material, design, and role of the fins may explain these differing outcomes. Further testing and optimization of fin design could potentially improve both aspects.

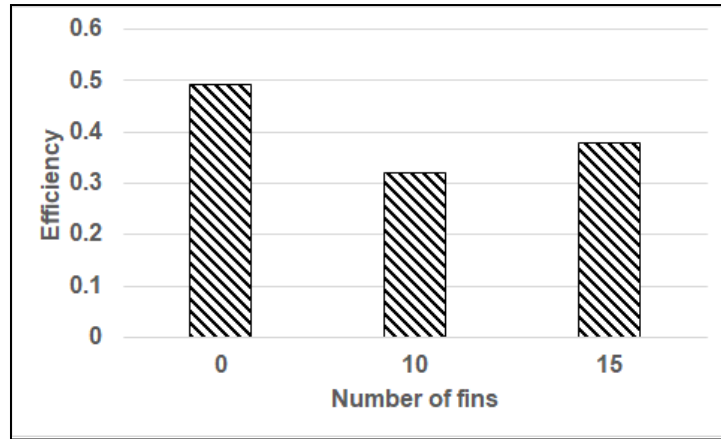


Figure 4 Efficiency versus number of fins

As given in figure 4, the system has the highest efficiency when there are no fins. This suggests that, for this particular setup or system, fins may not be necessary, or that their presence introduces factors that reduce efficiency. It could be that without fins, the system is operating more optimally, perhaps due to fewer physical limitations or friction losses that fins might introduce.

When 10 fins are added, efficiency drops significantly. This might indicate that there's an optimal number of fins that enhances efficiency, but beyond that number (or a certain configuration), adding more fins may cause turbulence, resistance, or other inefficiencies. It's also possible that the additional fins increase the surface area or lead to increased drag, causing a decrease in overall efficiency.

Adding 15 fins increases efficiency slightly compared to 10 fins but does not reach the level of having no fins. This suggests that while more fins might help somewhat, they might still not be ideal for maximizing efficiency. The system could be approaching a point of diminishing returns, where additional fins don't contribute significantly to the overall performance.

Adding fins increases the surface area of a system (such as a heat exchanger). While increasing surface area can improve heat exchange or other processes, there might be a point at which the increased surface area leads to diminishing returns. Too many fins can lead to excessive resistance or turbulence. In systems where fins are used (like in cooling devices or air movement), adding fins may cause more drag or friction, reducing the overall efficiency. This could explain why efficiency drops when the number of fins increases. In a heat transfer scenario (like a radiator or engine cooling system), adding fins may initially improve performance by providing more surface area for heat exchange. However, as the number of fins increases, the flow of air or coolant might become less efficient, leading to lower efficiency.

This graph indicates that there may be an optimal number of fins for maximizing efficiency, and that both too few or too many fins may reduce the system's overall performance. The data suggests that 0 fins might be the best for efficiency, while adding fins (especially around 10 fins) seems to cause inefficiencies. Adding more fins (like 15) doesn't completely solve this issue but provides a slight improvement over 10 fins.

4. Conclusion

Based on the data presented across the figures and the analysis provided, the following conclusions can be drawn: There is a clear positive correlation between the number of fins and the freshwater mass produced. As the number of fins increases from 0 to 15, the freshwater mass also increases (from 1.20 kg to 1.40 kg). Fins seem to help in increasing the mass of freshwater, likely by providing a larger surface area that encourages water retention or accumulation. This increase in mass might be due to effects like surface tension, capillary action, or condensation, which are enhanced by the increased surface area from the fins. The heat transfer rate decreases as the number of fins increases. This is an unexpected result since fins are generally designed to increase surface area and thus improve heat transfer. However, the data suggests that after a certain point, the fins may interfere with each other, or the increased surface area could hinder effective airflow or water flow, reducing the heat transfer rate. The data indicates a trade-off between increasing freshwater retention and maintaining efficient heat transfer. While adding fins increases the freshwater mass (Figure 2), it also reduces the heat transfer rate (Figure 3), suggesting that the increased surface area for water retention may obstruct or complicate the heat dissipation process. The system shows the highest efficiency when there are no fins (0

fins). As the number of fins increases, efficiency decreases. This drop is particularly significant when the number of fins increases from 0 to 10, but there is a slight recovery with 15 fins. This suggests that while fins may help with freshwater retention, they reduce efficiency in the system. Adding fins creates more drag, friction, or turbulence, which could hinder the overall system's performance. The system likely reaches a point of diminishing returns, where adding more fins doesn't provide substantial benefits and may even introduce inefficiencies. The addition of fins is likely leading to a conflict between their role in enhancing freshwater retention and their role in optimizing heat transfer. While fins help with water retention (Figure 2), their added surface area creates more resistance and thermal barriers, reducing the system's efficiency (Figure 4) and hindering heat transfer (Figure 3).

Further testing and refinement of the fin design, taking into account factors like material properties, shape, and spacing, would be required to achieve the optimal balance for both mass retention and heat transfer. Additionally, exploring the trade-offs between these two functions could lead to a more efficient and effective system.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in this work.

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