# Hybrid Cooling System Using Air and Water

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## ABSTRACT

Cooling systems are critical for preventing overheating and improving energy efficiency. Traditional air coolers have limitations in performance and resource usage. This project proposes a Hybrid Cooling System Using Air and Water to enhance heat transfer and reduce energy consumption.

## 1 INTRODUCTION

Effective cooling is essential across various sectors to maintain optimal conditions, ensure safety, and enhance energy efficiency. Traditional air cooling systems, though widely used, often face limitations in cooling capacity and high energy consumption. With rising global temperatures and increasing environmental concerns, there is a growing demand for more efficient and sustainable cooling technologies. This project presents a Hybrid Cooling System Using Air and Water, which combines air and evaporative water cooling to improve heat transfer and reduce energy usage. By leveraging the strengths of both methods, the system offers a reliable and eco-friendly solution suitable for industrial, commercial, and residential applications.

## 2 MOTIVATION

This project aims to develop an energy-efficient and eco-friendly cooling system by combining direct and indirect evaporative cooling methods. Traditional cooling systems consume high amounts of energy and electricity. By procuring components and assembling the system ourselves, we aimed to create a functional prototype that demonstrates improved cooling performance with reduced energy consumption and is suitable for sustainable applications.

The motivation for this project includes:

- Determining the heat transfer coefficient of the system
- Comparing the system's performance with conventional cooling towers
- Evaluating the power requirement to assess energy efficiency

## 3 METHODOLOGY

In the first experiment, indirect cooling was carried out using a spiral copper tube to enable heat exchange between water and air without direct contact. Hot air was introduced into the setup using a hair dryer, simulating high-temperature conditions. At the same time, cool water was pumped into the copper tube using an aquarium pump, ensuring a steady flow. As the hot air flowed around the copper tube, heat was transferred through the copper walls from the air to the water, lowering the air temperature. The heated water exited the tube after the exchange, and temperature readings of both the air and water at the inlet and outlet were recorded to evaluate the system's cooling performance. In the second experiment, a hybrid cooling system was implemented to enhance thermal performance by integrating both direct and indirect cooling mechanisms. Hot air is blown into a plastic chamber where it passes over spiral copper coils cooled by circulating water, utilizing convective heat transfer to remove heat from the air without direct contact. Simultaneously, a water sprinkler introduces a fine mist that absorbs heat from the air, evaporating and lowering the air temperature through the evaporative cooling process. A hair dryer ensures consistent hot air flow, while a thermocouple measures the final air temperature to evaluate cooling efficiency. Proper sealing and design adjustments were made to minimize leakage and maintain controlled airflow. This dual-action cooling system combines the benefits of both convective and evaporative cooling, improving overall thermal management.

## 4 SETUP EXPERIMENT

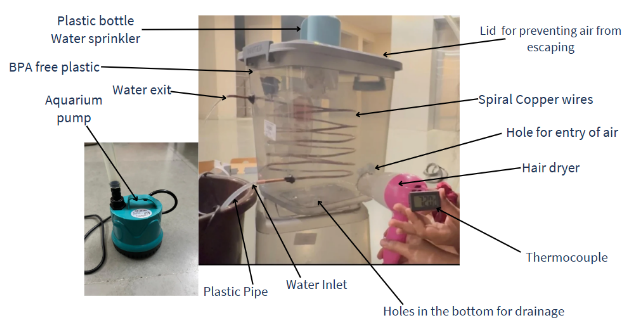


**Figure 1: Experimental Setup**

**System Description:**

- **Plastic Bottle / BPA-Free Plastic Chamber:** Acts as the main body where heat exchange takes place.
- **Spiral Copper Wires:** These serve as the heat exchanger. Hot air passes over them and transfers heat to the copper, which is continuously cooled by circulating water.

- **Hair Dryer:** Used as a source of hot air. The air enters the chamber through a designated hole.
- **Lid:** Prevents air from escaping, ensuring that air flows through the intended cooling path.
- **Water Inlet and Plastic Pipe:** Deliver cool water into the chamber, powered by an aquarium pump.
- **Aquarium Pump:** Circulates water through the copper coils to absorb and carry away heat.
- **Water Exit and Drain Holes:** Allow warm water to exit the system and enable any excess water to drain out.
- **Thermocouple:** Measures the temperature of the air after cooling, used to assess the efficiency of the setup.

# 5 CHALLENGES FACED

## 5.1 During Setup

- **Unstable Mesh Support:** The mesh used to remove moisture from the cool air couldn't hold the bottle stably so instead we used the lid.
- **Improper Piping:** Initially we used the PVC pipe as the sprinkler, but that led to unstable water flow paths so instead we used the bottle with holes as the sprinkler.
- **Water Drainage Issues:** Holes were made at the bottom instead of the sides for drainage as that was causing leaks and the other leaks were stopped by using M-seal.

## 5.2 During Experiment

- **Thermocouple Interference:** Contact with sprinkler water caused artificially low temperature readings.
- **Evaporative Effects:** Moisture in the air affected readings, making them less indicative of actual air cooling.
- **External Environment Influence:** Assumed isolation failed; ambient conditions caused fluctuations in results.
- **Inconsistent Water Flow:** Pump pressure variations led to uneven cooling across the copper coils.
- **Air Leaks:** Gaps in the system allowed hot air to escape, leading to unreliable airflow and cooling data.

# 6 CALCULATION

## 6.1 For experiment 1:

**Readings of Water :**

$$T_i = 20.7\,^\circ\mathrm{C}$$
$$T_e = 23.3\,^\circ\mathrm{C}$$

**Film Temperature:**

$$\begin{aligned} T_{\text{film}} &= \frac{T_{\text{wall}} + T_{\text{water, avg}}}{2} \\ &= \frac{42.6 + \left(\frac{20.7+23.3}{2}\right)}{2} \\ &= 32.3\,^\circ\mathrm{C} \end{aligned}$$

**Properties of Water at** $32.3\,^\circ\mathrm{C}$:

$$\begin{aligned} \mu &= 0.75 \times 10^{-3}\,\mathrm{kg/(m \cdot s)} \\ C_p &= 4.178\,\mathrm{kJ/(kg \cdot K)} \\ \rho &= 995\,\mathrm{kg/m^3} \end{aligned}$$

**Flow Rate:**

$$\text{Volume flow rate} = \frac{500\,\mathrm{mL}}{75\,\mathrm{s}} = 0.0067\,\mathrm{L/s}$$
$$\dot{m}_w = 0.0067\,\mathrm{kg/s}$$

**Heat Transfer Rate:**

$$\begin{aligned} \dot{Q} &= \dot{m}_w C_p \Delta T \\ &= 0.0067 \times 4.178 \times 10^3 \times (23.3 - 20.7) \\ &= 72.8\,\mathrm{W} \end{aligned}$$

$$\dot{Q}_w = \dot{Q}_{\text{air}}$$

## Readings of Air:

**Temperatures:**

$$T_i = 72\,^\circ\mathrm{C}$$
$$T_e = 46.5\,^\circ\mathrm{C}$$

**Film Temperature:**

$$\begin{aligned} T_{\text{film, air}} &= \frac{T_{\text{wall}} + T_{\text{air, avg}}}{2} \\ &= \frac{42.6 + \left(\frac{46.5+72}{2}\right)}{2} \\ &= 50.925\,^\circ\mathrm{C} \end{aligned}$$

**Properties at** $T_{\text{film, air}} = 50.925\,^\circ\mathrm{C}$:

$$\begin{aligned} \rho &= 1.092\,\mathrm{kg/m^3} \\ C_p &= 1007\,\mathrm{J/(kg \cdot K)} \\ \mu &= 1.963 \times 10^{-5}\,\mathrm{kg/(m \cdot s)} \\ \nu &= 1.798 \times 10^{-5}\,\mathrm{m^2/s} \\ Pr &= 0.7228 \end{aligned}$$

**Heat Transfer:**

$$\begin{aligned} \dot{Q}_{\text{air}} = \dot{Q}_w &= 72.8\,\mathrm{W} = \dot{m}_{\text{air}} C_p \Delta T \\ 72.8 &= \dot{m}_{\text{air}} \times 1007 \times (72 - 46.5) \\ \dot{m}_{\text{air}} &= \frac{72.8}{1007 \times 25.5} \\ &= 0.00283\,\mathrm{kg/s} \end{aligned}$$

**Flow Arrangement:**
This is a **cross-flow** heat exchanger.
Considering both fluids are **non-mixing**, the correction factor is:

$$F = \frac{\Delta T_{\text{LMTD, counterflow}}}{\Delta T_{\text{LMTD, crossflow}}}$$

**LMTD and Effectiveness Factor Calculation**

**LMTD Formula:**

$$\Delta T_{\text{LMTD}} = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}$$

**Temperature Differences:**

$$\Delta T_i = T_{hi} - T_{ce} = 72 - 23.3 = 48.7^\circ\text{C}$$
$$\Delta T_e = T_{he} - T_{ci} = 46.5 - 20.7 = 25.8^\circ\text{C}$$

$$\Delta T_{\text{LMTD}} = \frac{48.7 - 25.8}{\ln\left(\frac{48.7}{25.8}\right)} = \frac{28.1}{0.793} = 36.046^\circ\text{C}$$

**For Correction Factor (F), we need $R$ and $S$:**

$$R = \frac{T_{1i} - T_{1e}}{T_{2e} - T_{2i}} = \frac{20.7 - 23.3}{46.5 - 72} = 0.101$$
$$S = \frac{T_{2e} - T_{2i}}{T_{1i} - T_{2i}} = \frac{46.5 - 72}{20.7 - 72} = 0.497$$

From the graph, we find:

$$F = 0.99$$

$$\Delta T = F \cdot \Delta T_{\text{LMTD}} = 0.99 \times 36.046 = 35.68^\circ\text{C}$$

**Heat Transfer Equation:**

$$Q = UA\Delta T$$

$$72.8 = U \cdot A \cdot 35.68$$

**Area of heat transfer surface:**

$$A = 2\pi r_o l = 2\pi(0.0025) \times 2.95 = 0.0463\,\text{m}^2$$

**Solving for $U$:**

$$72.8 = U \cdot 0.0463 \cdot 35.68$$

$$U = \frac{72.8}{0.0463 \times 35.68} = 44.068\,\text{W/m}^2 \cdot {}^\circ\text{C}$$

## For Efficiency

Power (Hair Dryer) = 1000 W
Power (Pump) = 18 W (per pump)
minimum capacity is of air
**Efficiency**

$$\eta = \frac{\dot{Q}_{\text{air}}}{P_{\text{total}}} \times 100 = \frac{72.8}{1018} \times 100 = 7.15\%$$

**Effectiveness** (minimum capacity is of air)

$$\varepsilon = \frac{T_{\text{hot,in}} - T_{\text{hot,out}}}{T_{\text{hot,in}} - T_{\text{cold,in}}} \times 100 = \frac{72 - 46.5}{72 - 20.7} \times 100 = 50\%$$

**Power Requirement**

$$P_{\text{required}} = P_{\text{dryer}} + P_{\text{pump}} = 1000 + 18 = 1018\,\text{W}$$

## 6.2 For experiment 2:

The mass flow of air and water is the same as in experiment 1 at the inlet.

$$\dot{m}_{\text{air}} = 0.00283\,\text{kg/s}, \quad \dot{m}_{\text{spiral}} = 0.0067\,\text{kg/s}$$

## Readings:

For air:

$$T_{\text{hi}} = 72^\circ C, \quad T_{\text{he}} = 30.1^\circ C, \quad T_{\text{avg, air}} = 51.05^\circ C$$

For sprinkler:

$$T_{\text{ci}} = 20.7^\circ C, \quad T_{\text{ce}} = 23.7^\circ C, \quad T_{\text{avg, sprinkler}} = 21.85^\circ C$$

For spiral water:

$$T_{\text{ci}} = 20.7^\circ C, \quad T_{\text{ce}} = 21.9^\circ C, \quad T_{\text{avg, spiral}} = 21.3^\circ C$$

## Properties at $T_{\text{avg}}$

$$Cp_{\text{air}} = 1007\,\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}, \quad \rho_{\text{air}} = 1.092\,\text{kg}\cdot\text{m}^{-3}$$

$$Cp_{\text{spiral}} = 4180.7\,\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}, \quad Cp_{\text{sprinkler}} = 4180.2\,\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$$

$$h_{\text{fg}} = 2450\,\text{kJ}\cdot\text{kg}^{-1}$$

## Mass Balance

For air and spiral water inlet and outlet, the mass flow rates are the same.

For the sprinkler:

$$\dot{m}_{\text{in}} = \dot{m}_{\text{out}} + \dot{m}_{\text{evap}} \quad \text{(Some evaporation will be there)}$$

## Energy Balance (For the Chamber as a System)

Assuming no heat loss to the surroundings or through the plastic chamber (steady-state):

$$\dot{Q}_{\text{in}} = \dot{Q}_{\text{out}}$$
$$\dot{Q}_{\text{spiral}} + \dot{Q}_{\text{sprinkler}} = \dot{Q}_{\text{air}}$$

$\dot{m}_{\text{spiral}} \cdot Cp \cdot (T_{\text{ce}} - T_{\text{ci}}) + \dot{m}_{\text{sprinkler}} \cdot Cp \cdot (T_{\text{ce}} - T_{\text{ci}}) + \dot{m}_{\text{evap}} \cdot h_{\text{fg}} = \dot{m}_{\text{air}} \cdot Cp \cdot (T_{\text{hi}} - T_{\text{he}})$

Substituting values:

$0.0067 \times 4180.7 \times (21.9 - 20.7) + 0.0067 \times 4180.2 \times (23.7 - 20.7) + \dot{m}_{\text{evap}} \cdot 2450 = 0.00283 \times 1007 \times (72 - 30.1)$

$$119.41 = 33.613 + 84.022 + \dot{m}_{\text{evap}} \cdot h_{\text{fg}}$$

$\dot{m}_{\text{evap}} \cdot h_{\text{fg}} = 1.8\,\text{J/s}$ ($\dot{m}_{\text{evap}}$ is very low, so Neglecting this)

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{air}} = 119.41\,\text{J/s}$$

## LMTD (Logarithmic Mean Temperature Difference)

F is approx 1 in experiment 1 and in experiment 2 there is some phase change involved, so taking F =1

**For the air and sprinkler:**

$$\Delta T_{\text{lm1}} = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}$$

$$\Delta T_i = T_{\text{hi}} - T_{\text{ce}} = 72 - 23.7 = 48.3^\circ C$$
$$\Delta T_e = T_{\text{he}} - T_{\text{ci}} = 30.1 - 20.7 = 9.4^\circ C$$
$$\Delta T_{\text{lm1}} = \frac{48.3 - 9.4}{\ln\left(\frac{48.3}{9.4}\right)} = 23.767^\circ C$$

For the air and spiral:

$$\Delta T_i = T_{\text{hi}} - T_{\text{co}} = 72 - 21.9 = 50.1^{\circ}C$$

$$\Delta T_e = T_{\text{he}} - T_{\text{ci}} = 30.1 - 20.7 = 9.4^{\circ}C$$

$$\Delta T_{\text{lm2}} = \frac{50.1 - 9.4}{\ln\left(\frac{50.1}{9.4}\right)} = 24.323^{\circ}C$$

Taking the average for LMTD:

$$\Delta T_{\text{lm}} = \frac{Q_{\text{sprinkler}} \cdot \Delta T_{\text{lm1}} + Q_{\text{spiral}} \cdot \Delta T_{\text{lm2}}}{Q_{\text{sprinkler}} + Q_{\text{spiral}}}$$

$$\Delta T_{\text{lm}} = \frac{84.022 \cdot 23.767 + 33.613 \cdot 24.323}{119.41} = 23.924^{\circ}C$$

## Calculation of $U$

$$\dot{Q}_{\text{air}} = U \cdot A \cdot \Delta T_{\text{lm}}$$

$$119.41 = U \cdot 2 \cdot \pi \cdot \frac{0.005}{2} \cdot 2.95 \cdot 23.924$$

$$U = 107.71\,\text{W/m}^2 \cdot \text{K}$$

## For Efficiency

Power (Hair Dryer) = 1000 W
Power (Pump) = 18 W (per pump)
Total Pump Power = 2 ×18 = 36 W
minimum capacity is of air
**Efficiency**

$$\eta = \frac{\dot{Q}_{\text{air}}}{P_{\text{total}}} \times 100 = \frac{119.41}{1036} \times 100 = 11.5\%$$

**Effectiveness** (minimum capacity is of air)

$$\varepsilon = \frac{T_{\text{hot,in}} - T_{\text{hot,out}}}{T_{\text{hot,in}} - T_{\text{cold,in}}} \times 100 = \frac{72 - 30.1}{72 - 20.7} \times 100 = 81.676\%$$

**Power Requirement**

$$P_{\text{required}} = P_{\text{dryer}} + 2 \times P_{\text{pump}} = 1000 + 36 = 1036\,\text{W}$$

# 7 RESULTS

## 7.1 Experiment 1:

**overall heat transfer coefficient**

$$U = 44.068\,\text{W/m}^2 \cdot \text{K}$$

**Heat removed**

$$\dot{Q}_{\text{air}} = 72.8\,\text{W}$$

**Efficiency**

$$\eta = 7.15\%$$

**Effectiveness**

$$\varepsilon = 50\%$$

**Power Requirement**

$$P_{\text{required}} = 1018\,\text{W}$$

## 7.2 Experiment 2:

**overall heat transfer coefficient**

$$U = 107.71\,\text{W/m}^2 \cdot \text{K}$$

**Heat removed**

$$\dot{Q}_{\text{air}} = 119.41\,\text{W}$$

**Efficiency**

$$\eta = 11.5\%$$

**Effectiveness**

$$\varepsilon = 81.676\%$$

**Power Requirement**

$$P_{\text{required}} = 1036\,\text{W}$$

## 7.3 Comparison with conventional cooling towers

While the overall efficiency of our hybrid cooling system is 11.5%, which is lower than that of large-scale industrial cooling towers, our model stands out in terms of portability, lower water usage, reduced power consumption, and better adaptability to dry weather. Another reason for lower efficiency is due to the fact that we are adding the heat ourselves with an external source such an hair dryer. The high effectiveness (81.68%) and dual-action cooling make it a strong candidate for compact and sustainable applications.

# 8 CONCLUSION

The efficiency of the first experiment (indirect cooling) was 7.15% which was moderate, with a heat transfer rate of 72.8W and an overall heat transfer coefficient of 44.068W/m²·°C. In contrast, the hybrid cooling experiment achieved a significantly higher heat transfer rate of 119.41W, an overall heat transfer coefficient of 107.71W/m²·K, and an effectiveness of 81.7% and an overall efficiency of 11.5%.

In conclusion, the hybrid cooling system—combining air and water cooling—demonstrated significantly higher efficiency and effectiveness than the conventional indirect cooling setup. This confirms that integrating both convective and evaporative cooling provides a more powerful and sustainable solution for heat management.

# 9 REFERENCES

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