Study and analysis of pin fin and plate fin under different working conditions

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Abstract

Extended surfaces have made significant advancements in the field of heat transfer, and ongoing global research continues to explore their potential. In this context, the current study focuses on pin fins and plate fins. Two configurations with identical surface areas were constructed using mild steel and evaluated for the 2021–22 and 2022–23 sessions across different seasons. Convective heat transfer coefficients were calculated as part of the analysis. Subsequently, tip temperatures and heat transfer rates were determined through both analytical and experimental methods, yielding comparable results. The study concluded that, as short fins, plate fins demonstrate superior tip temperatures and convective heat transfer rates compared to pin fins. Additionally, heat transfer rates were highest in summer due to greater temperature gradients, moderate during the rainy season, and lowest in winter.

1. Introduction

According to Freegah et al. (2020), the enhancement of thermal performance through design optimization of heat sinks has garnered significant attention in recent years. Similarly, Ganesh and Prakash (2019) highlighted that all engineering systems generate heat during operation, and failure to dissipate this heat effectively can lead to component malfunction. To prevent overheating, extended surfaces or fins are utilized to facilitate heat removal from the system. Shitole et al. (2018) further explained that convection is the heat transfer mechanism between a surface and the adjacent fluid, emphasizing that the rate of heat transfer can be improved by either increasing the surface area or enhancing the convective heat transfer coefficient. While increasing the heat transfer coefficient may require larger or more powerful pumps or fans, this approach may not always be practical or sufficient. Instead, adding fins made from highly conductive materials, such as aluminum, is a viable solution to increase surface area. Finned surfaces are widely used in practice and can significantly enhance the rate of heat transfer, often by several times. Building on these principles, the current research focuses on analyzing the performance of plate fins and pin fins under various conditions.

Following points research objectives of proposed research work:

a) Analysis of tip temperatures of plate fins and pin fins;
b) Analysis of convective heat transfer rates of plate fins and pin fins;
c) Analysis of heat transfer rates in different working conditions.

2. Literature Review

Table 2.1 presents the contributions of researchers in the field of pin fin heat transfer and plate fin heat transfer.

Table 2.1: Noteworthy Contributions of Researchers in the Field of Proposed Work

S. No	Researcher (Year)	Research Contribution
1.	Li et al. (2023)	Conducted comprehensive experimental studies on frost formation patterns in plate-fin heat exchangers for cryogenic applications, developing new defrosting straties.
2.	Kumar et al. (2022)	Developed novel offset strip fin designs incorporating vortex generators, achieving 27% enhancement in heat transfer with minimal pressure drop penalty.
3.	Liu et al. (2021)	Studied the effects of flow maldistribution on thermal performance, developing new header designs to improve flow distribution by up to 25%.
4.	Buyruk and Karabulut (2020)	Analysis of plate heat exchangers with different fin types
5.	Ganesh and Prakash (2019)	Following are the contributions of the researchers: (a) As the air velocity increases the rate of heat transfer increases. (b) The heat transfer rate is significantly influenced by geometry of perforations. (c) Using of Square perforations of 12 mm reduces the weight by the 23.6% compare to solid fins.
6.	Sharma et al (2018)	Heat dissipation from the rectangular geometry and best material for fins is copper.
7.	Venkateshwaran and Mural (2018)	The vital performance factor to consider should be area of contact to the atmosphere and the material characteristics with respect to effectiveness of

		the Radiating Pin fins.
8.	Gnanasekaran and Balaji (2018)	Deviations in results tend to increase with increase in time interval due to increased accumulation of noise.
9.	Saravanan and Umesh (2018)	The research work provides a comparison of fluid flow and heat transfer characteristics for micro pin fin heat sink and micro channel pin fin heat sink with unpinned micro channel heat sink.
10.	Avhad et al. (2018)	The research work provides comparison of Al with existing materials.
11.	Kumar and Sahu (2018)	Transient thermal analysis of different fin geometries and their comparison.
12.	Sangaj et al. (2018)	Comparison of fins of different materials and geometries is made.
13.	Yadav and Pandey (2017)	Thermal analysis of triangular shaped fins for different parametric conditions was accomplished.
14.	Ali (2017)	Thermal properties of solid and hollow fins with and without perforations are evaluated.
15.	Dange and Deshmukh (2017)	Experimental analysis of heat transfer variation and its enhancement of the cylindrical, staggered pin fin heat sink under constant heat flux condition
16.	Kaviyarasu and Saravanan (2017)	Aluminum 6063 rod for three various surface roughness was fabricated and tested for the heat transfer coefficient and heat transfer rate.
17.	Kumar and Choudhary (2017)	Investigations on Reynold's and Nusselt's number on fin materials and characteristics.
18.	Ambesange et al. (2017)	Analysis of heat transfer from dimple pin fin of circular cross section.
19.	Yenkar et al. (2017)	Analysis of heat transfer characteristics over a flat surface equipped with hollow cylindrical cross- sectional pin fins in a rectangular channel under forced convection.
20.	Reddy et al. (2017)	The design of heat sink device is predicated upon optimizing the opposite demands of maximizing thermal dissipation rate.
21.	Gowda and Yadav (2017)	The research work reviews pin fin heat sinks of different cross- sections, low density versus high density pin configurations and more factors in figuring out what is required for an application.

22.	Gaikwad et al. (2017)	Quantification and comparison of forced convection and natural convection heat transfer enhancement of pin fin using different metals and to study the thermal performance of pin fin
23.	Agilan and Rajaparthiban (2017)	Aluminium reinforced silicon carbide particle composite possess improved operational potential for critical structural components due to its attractive properties when compared to monolithic materials.
24.	Jasim and Söylemez (2017)	The researchers introduced inclined perforating as a new approach to improve the performance of the pin fin.
25.	Rasel (2016)	Results of the research work shows that as the velocity increases, the heat transfer rate from the base increases and from the fin decreases.
26.	Gowreesh and Veeresh (2016)	In the research work, thermal Analysis is performed for various perforated fin extensions with varied diameter.
27.	Pande and Siras (2016)	In pin-fin heat sinks, the staggered arrangement of fins has lesser thermal resistance as compared to the inline arrangement of fins. The surface oatings on the fin surfaces could play critical role in enhancing heat transfer rate from fins.
28.	Soni (2016)	Elliptical fins can be a replacement for pin fins.

2.1 Gaps in the Research

Following points represent gaps in the research:

a) A limited research is available in the literature which focuses on comparative analysis of plate fins and pin fins; and

b) There is very limited research available which focuses on different combinations of different finp parameters and comparison among them.

And, on the basis of above mentioned research gaps, the topic of research has been presented asfollows:

Study and Analysis of Pin Fin and Plate Fin under different Working Conditions

3. Solution Methodology

The present section is devoted to the terms used in the research work, as presented in upcoming sub-section.

3.1 Terms used in the Research Work

During the research work, the following terms were used.

a) Film Temperature (T_f)

The film temperature (T_f) is the average of the surface and ambient temperatures:

$$T_f = \frac{T_s + T_\infty}{2} \tag{3.1}$$

It determines the average temperature between the surface and the ambient. It is used to estimate the properties of air (or any fluid) at the film temperature, such as thermal conductivity, kinematic viscosity, and Prandtl number.

b) Reynolds Number (ReRe)

The Reynolds number (Re) is calculated as:

$$R_e = \frac{u.L}{v} \tag{3.2}$$

…..where,

- u: Fluid velocity (m/s)
- L: Characteristic length (m)
- μ: Dynamic viscosity (Pa·s)
- ν: Kinematic viscosity ($m^2/sm^2/s$),

c) Nusselt Number (Nu)

For turbulent flow over a flat plate (based on the Dittus-Boelter equation):

$$N_u = 0.023 \times R_e^{0.8} \times P_r^{0.4} \tag{3.3}$$

Prandtl number, P_r (dimensionless) indicates the ratio of momentum diffusivity to thermal diffusivity. It relates convective heat transfer to thermal conductivity. Higher Nu implies better convective heat transfer.

d) Convective Heat Transfer Coefficient (h)

Convective heat transfer may be calculated using the following equation.

$$\mathrm{h} = \frac{\mathrm{N_u} \times k}{\mathrm{L}}, \mathrm{W/m^2C} \tag{3.4}$$

….where,

- N_u: Nusselt number
- k: Thermal conductivity of the fluid (W/m·K).
- L: Characteristic length (m).

It quantifies the heat transfer rate per unit area per unit temperature difference. Convective heat transfer coefficient is critical for determining how efficiently heat is transferred between the surface and the fluid.

e) Tip Temperature Equation

The tip temperature equation is presented as follows:

The temperature distribution of the fin may be obtained from the following equation.

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{cosh.m.(L - x)}{cosh.m.L} \tag{3.5}$$

.....where,

T = Unknown temperature (°C)

$T_\infty = Ambient\ temperature$ (°C)

$T_0 = Base\ temperature$ (°C)

L = Length of fin (m)

x = Length of fin at a point from the base (m)

In equation (4.9), the value of m is obtained using the following equation:

$$m = \sqrt{\frac{h.P}{k.A_c}} \tag{3.6}$$

Where, h = convective heat transfer coefficient
P = Perimeter (m)
k = Thermal conductivity (W/m°C)
A_c = Area of cross-section

f) Heat Transfer Rate $(\dot{Q})$

Heat transfer rate $(\dot{Q})$ is calculated by the following equation.

$$\dot{Q} = \sqrt{h \times P \times k \times A_C \times (T_0 - T_\infty)} \times \tanh{(m \times l_c)} \tag{3.7}$$

…..where,
P: Perimeter (m)
l_c: Effective length of the fin (m)

4. Case Study

The present section is devoted to the problem formulation and its solution and also acts as the preparation phase for determination of properties of plate fins and pinned fins for the purpose of their comparison, as presented in upcoming sub-sections.

4.1 Problem Formulation

Following points represent the details of problem formulation.

a) After investigations on the research gaps and finalization of objectives of the research work, first of all, with the help of experts' opinion and the survey of literature, physical models of plate fins and pinned fins were created. For this purpose, circular pins (rods) as well as plates were used, the details of which are presented as follows.

Table 4.1: Specifications of Plate fins and Pinned fins

S. No	Specification	Fin types	
		Plate fins	Pinned fins
1.	Length (l)	80 mm	80 mm
2.	Width (w)	2 mm	*****
3.	Height (h)	100 mm	100 mm
4.	Diameter (d)	*****	6.5 mm
5.	Base dimensions	100 mm × 80 mm	100 mm × 80 mm
6.	Material	Structural steel	Structural steel

b) In order to keep similarity between them, the surface areas of both the models were kept same, using the following equation.

Total surface area of plates = Total surface area of pins

$$2\times l\times h + 2\times l\times w + h\times w = \pi\times d\times h + (\pi/4)\times d^2 \tag{4.1}$$

On putting the values of specifications of plates and pins in above equation, we get

$$1 \text{ plate fin} = 10 \text{ pin pins} \tag{4.2}$$

c) For the purpose of calculations, models of 3 plates and 30 pins were created, and their unwanted surfaces were properly insulted. The details of models are presented as follows.

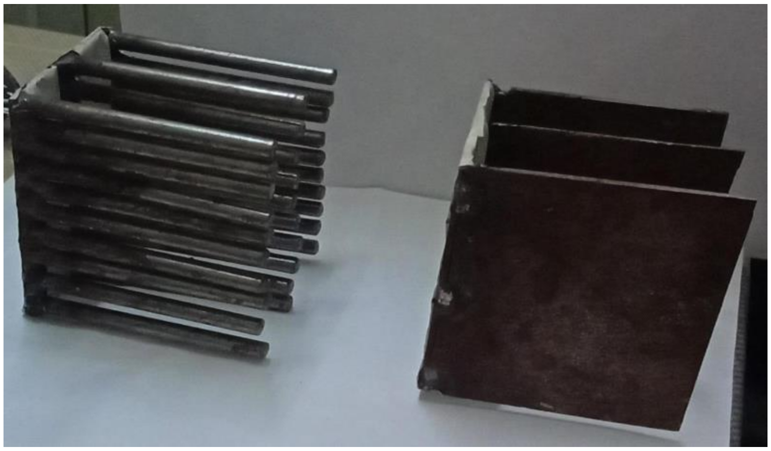


Figure 4.1: Details of Fin Models

4.2 Problem Solution

In order to solve the problem, environmental conditions in different seasons were considered for the period of two sessions, 2021-2022 and 2022-2023, and analytical as well experimental approaches were used, the details of which are presented in as follows.

4.2.1 Analytical Approach

In order to solve the problem analytically, first of all the values of coefficient of convective heat transfer (h) was calculated for winter season of Bhopal city for the session 2021-2022, as follows, assuming steady state conditions.

a) Gather Historical Weather Data

Based on available data for Bhopal in December 2021, the average temperatures were:

- **Average High Temperature**: 25°C (77°F)
- **Average Low Temperature**: 14°C (57°F)
- **Average Temperature**: 19°C (66°F)

Wind speeds during this period were generally low, averaging around 3 to 7 mph (approximately 1.3 to 3.1 m/s).

b) Define Surface and Conditions

Assume:

- **Surface Geometry**: Flat plate
- **Surface Temperature** (Ts): 40°C
- **Ambient Temperature** (T∞): 19°C
- **Wind Speed** (u): 2 m/s

c) Calculate Film Temperature

The film temperature (T_f) is the average of the surface and ambient temperatures:

$$T_f = \frac{T_S+T_\infty}{2} = \frac{40+19}{2} = 29.5℃ \tag{4.3}$$

d) Determine Air Properties at Film Temperature

At T_f=29.5℃, the properties of air are approximately:

- **Thermal Conductivity** (k): 0.0263 W/m·K
- **Kinematic Viscosity** (ν): 16.3×10^{-6} m^2/s
- **Prandtl Number** (Pr): 0.707

e) Calculate Reynolds Number

The Reynolds number (Re) is calculated as:

$$R_e = \frac{u.L}{v} \tag{4.4}$$

Assuming a characteristic length (L) of 1 meter:

$$R_e = \frac{2 \times 1}{16.3 \times 10^{-6}} = 122{,}700 \tag{4.5}$$

f) Select Appropriate Correlation

For a flat plate in turbulent forced convection (Re>5×10^5), the Dittus-Boelter equation is suitable:

$$N_u = 0.023 \times R_e^{0.8} \times P_r^{0.4} \tag{4.6}$$

g) Calculate Nusselt Number

$$N_u = 0.023 \times 122{,}700^{0.8} \times 0.707^{0.4} = 393.5 \tag{4.7}$$

h) Determine Convective Heat Transfer Coefficient

$$\mathrm{h} = \frac{\mathrm{N_u} \times k}{\mathrm{L}} = 10.35\ \mathrm{W/m^2C} \tag{4.8}$$

Similarly, the convective heat transfer coefficients for different seasons were investigated for different atmospheric temperature values as follows.

Table 4.2: Values of convective heat transfer coefficients for different seasons

S.No	Session	Season	Atmospheric temperature (T_∞) (°C)	h value (round off values)
1.	2021-	Summer	34	20.93

2.	2022	Rainy	29	18.5
3.		Winter	19	10.35
4.	2022-2023	Summer	35	21.5
5.		Rainy	30	18.8
6.		Winter	20	15.5

In the next step, calculations for the tip temperature and heat transfer were accomplished. For this purpose, the following parameters were used.

Table 4.3: Parameters used for Tip temperature and heat transfer calculations

S. No	Property	Unit	Plate fin
1.	Material	*****	Structural Steel
2.	Cross section	mm^2	60
3.	Length of fin	mm	80
4.	Base temperature	°C	200
5.	Convection coefficient	W/m^2°C	From Table 4.1
6.	Ambient temperature	°C	From Table 4.1
7.	Thermal conductivity	W/m°C	50
8.	Number of fins	*****	3

The temperature distribution of the fin may be obtained from the following equation.

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{cosh.m.(L - x)}{cosh.m.L} \tag{4.9}$$

Where, T = Unknown temperature (°C)

$T_\infty = Ambient\ temperature$ (°C)

$T_0 = Base\ temperature$ (°C)

L = Length of fin (m)

x = Length of fin at a point from the base (m)

In equation (4.9), the value of m is obtained using the following equation:

$$m = \sqrt{\frac{h.P}{k.A_c}} \tag{4.10}$$

Where, h = convective heat transfer coefficient
P = Perimeter (m)
k = Thermal conductivity (W/m°C)
A_c = Area of cross-section

Table 4.4 shows the values of m×l values for different h values.

Table 4.4: m×l values for different h values

S.No	Session	Season	h value (round off values)	m values	m×l
1.	2021-2022	Summer	20.93	2.06633	0.165306
2.		Rainy	18.5	1.942679	0.155414
3.		Winter	10.35	1.453066	0.116245
4.	2022-2023	Summer	21.5	2.094278	0.167542
5.		Rainy	18.8	1.958367	0.156669
6.		Winter	15.5	2.06633	0.165306

From Table 4.4, one can analyze that all the obtained m×l values were less than 5, so therefore, the fins were considered as the fins of finite length, and in these cases, corrected lengths (l_c) were calculated which was obtained using following equation.

$$l_c = l + t/2 \tag{4.11}$$

Where lc = Corrected length (m)

l = Actual length (m)

t = thickness (for pin fins, diameter was used) (m)

Table 4.5 shows the values of corrected lengths for different h values.

Table 4.5: l_c values for different h values

S.No	Session	Season	h value (round off values)	l_c value (m)
1.	2021-2022	Summer	20.93	0.081
2.		Rainy	18.5	0.081
3.		Winter	10.35	0.081
4.	2022-2023	Summer	21.5	0.081
5.		Rainy	18.8	0.081
6.		Winter	15.5	0.081

In the next step, temperatures (T) at the tip (x = 0.08m) of fin were calculated using the following equation.

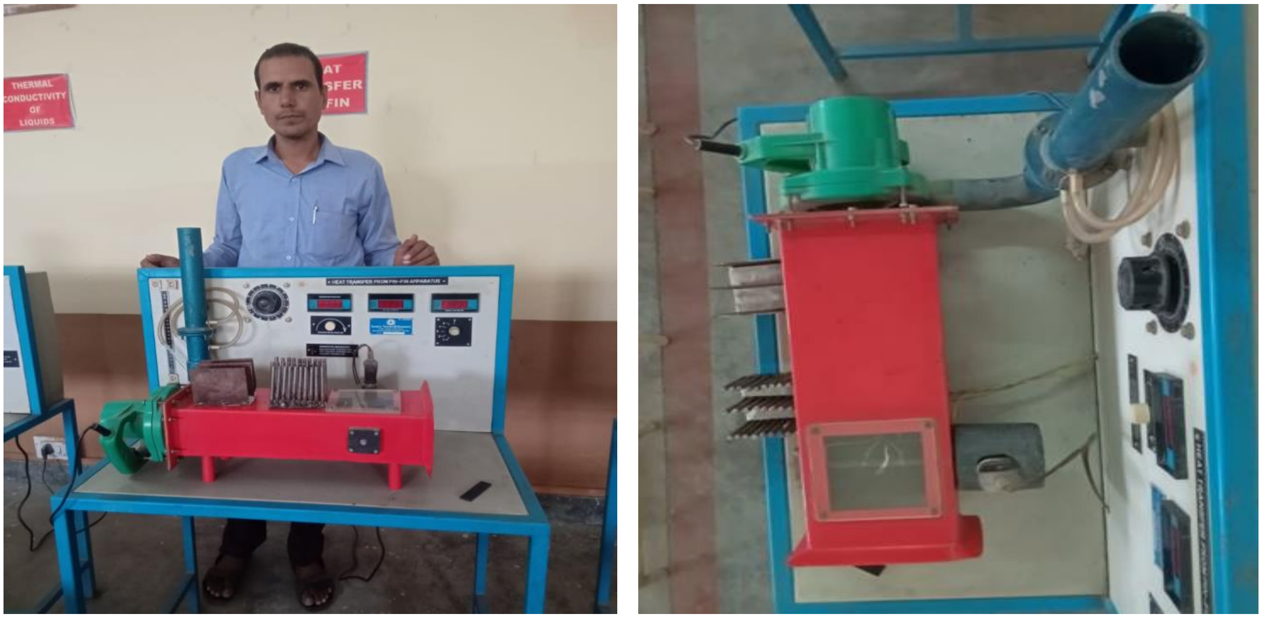
$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{cosh. m. (L - x)}{cosh. m. L} \tag{4.12}$$

In the next step, the rate of heat transfer from the surface was calculated using the following equation.

$$\dot{Q} = \sqrt{h \times P \times k \times A_C \times (T_0 - T_\infty)} \times \tanh{(m \times l_c)} \tag{4.13}$$

4.2.2 Experimental Approach

The results of the research work were also validated using experimental approach, under with the tip temperatures for different h values were recorded, and in turn, $\dot{Q}$ values were investigated. Figure 4.2 shows the arrangements used for experimental approach.



(a) (b)

Figure 4.2: Experimental Set up used in the Research work

5. Results and Discussion

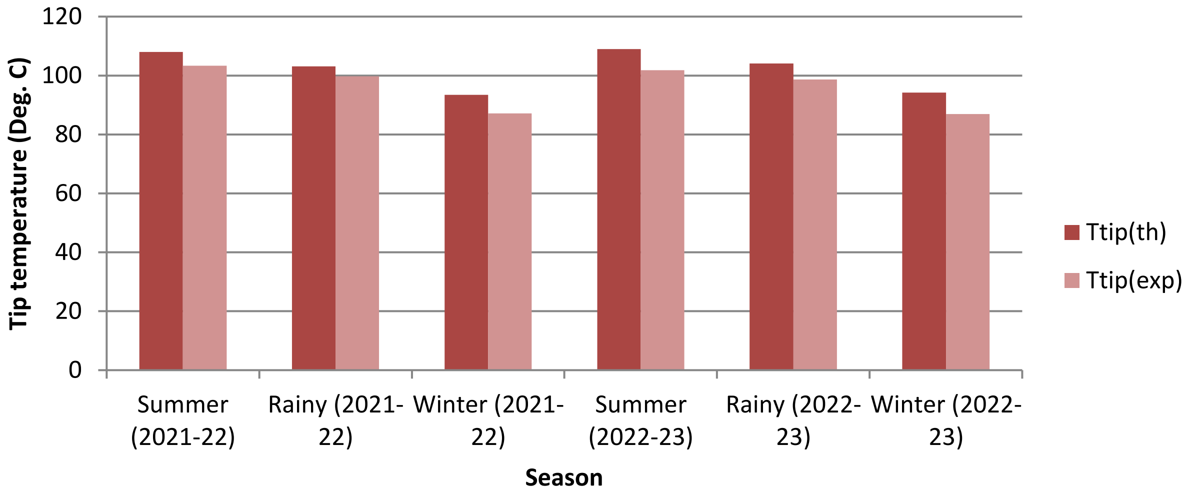
The present section is devoted to the results obtained as well as associated discussion, the details of which are presented in upcoming sub-sections.

5.1 Results

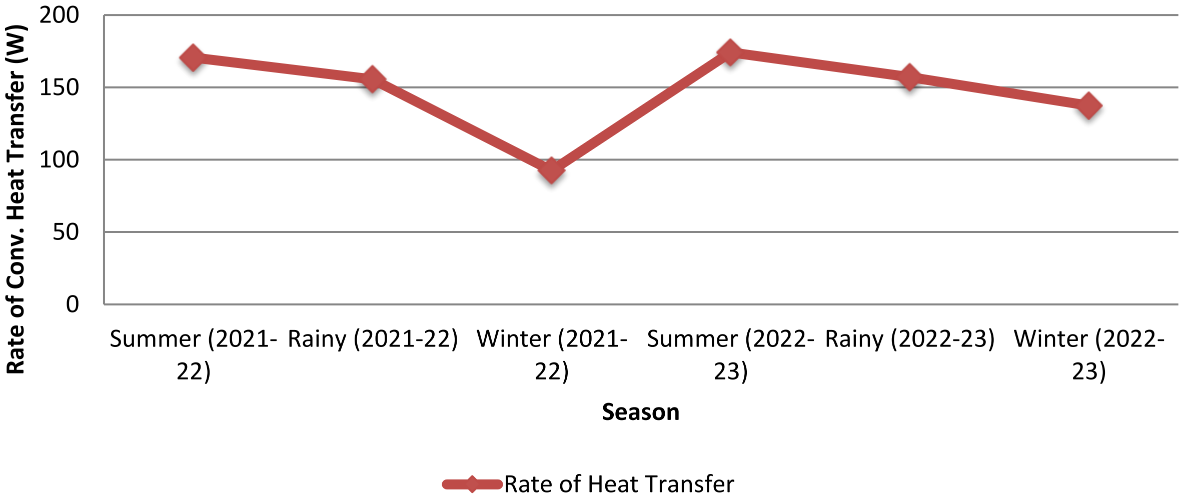
Table 5.1 and Figure 5.1 present the results of the research work for plate fin arrangement.

Table 5.1: Results of research Work for Plate fins

S.No	Session	Season	T_{tip}		$\dot{Q}$
			$T_{tip(th)}$	$T_{tip(exp)}$	
1.	2021-2022	Summer	107.9618	103.3	170.6415
2.		Rainy	103.0811	99.8	155.5394
3.		Winter	93.48358	87.1	92.43925
4.	2022-2023	Summer	108.9338	101.8	174.189
5.		Rainy	104.0663	98.7	157.1165
6.		Winter	94.22882	86.9	137.3573



(a) $T_{tip(th)}$ vs. $T_{tip(exp)}$



(b) Rate of Convective Heat Transfer

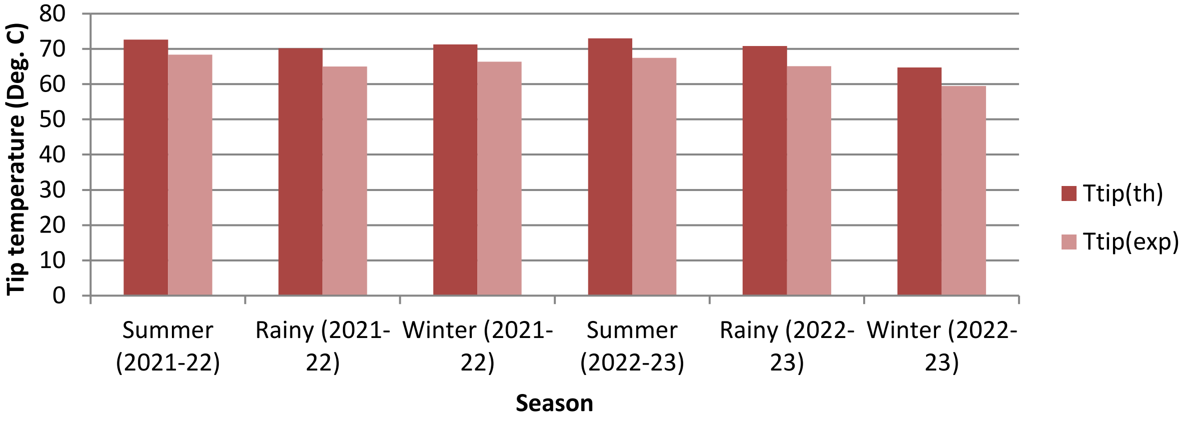
Figure 5.1: Graphical Representation of Results of Research work for Plate fins

Similarly, Table 5.2 and Figure 5.2 presents the results of research work for pin fin arrangement.

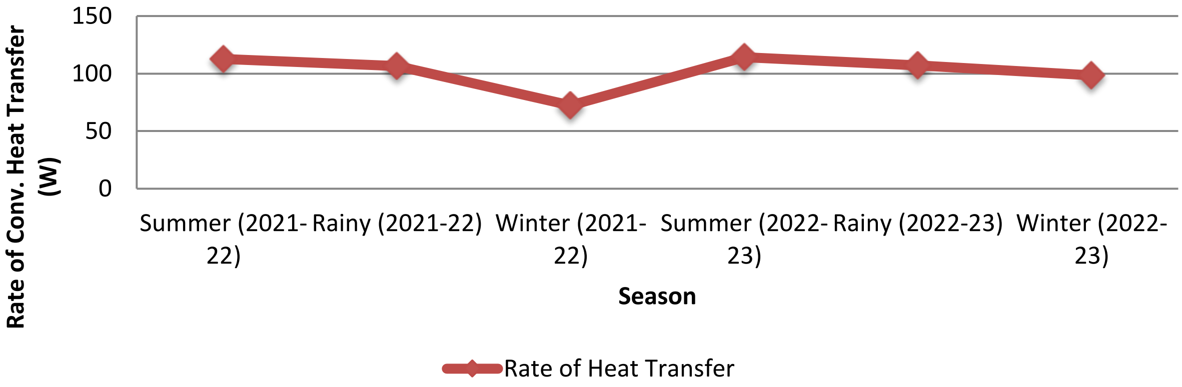
. **Table 5.2: Results of research Work for Pin fins**

S.No	Session	Season	T_{tip}		$\dot{Q}$
			$T_{tip(th)}$	$T_{tip(exp)}$	
1.	2021-2022	Summer	72.59551	68.35	112.7898

2.		Rainy	70.18909	64.98	106.4666
3.		Winter	71.23645	66.37	72.37679
4.	2022-2023	Summer	73.0238	67.44	114.2268
5.		Rainy	70.85445	65.12	107.0709
6.		Winter	64.7855	59.45	98.46228



(a) $T_{tip(th)}$ vs. $T_{tip(exp)}$



(b) Rate of Convective heat transfer

Figure 5.2: Graphical Representation of Results of Research work for Pin fins

Table 5.3 shows the percentage variations in values of tip temperatures for plate fins and pin fins, from which one can analyze that, at the differences between tip temperature values are less than 10 percent, the results of theoretical approach can be validated with the results of experimental approach.

Table 5.3: Validation of Results using theoretical and experimental approaches

S.No	Session	Season	Plate fin arrangement			Pin fin arrangement		
			$T_{tip(th)}$	$T_{tip(exp)}$	% variation	$T_{tip(th)}$	$T_{tip(exp)}$	% variation
1.	2021-2022	Summer	107.9618	103.3	4.318009	72.59551	68.35	5.848172
2.		Rainy	103.0811	99.8	3.183028	70.18909	64.98	7.42151
3.		Winter	93.48358	87.1	6.828557	71.23645	66.37	6.831404
4.	2022-2023	Summer	108.9338	101.8	6.548748	73.0238	67.44	7.646548
5.		Rainy	104.0663	98.7	5.156617	70.85445	65.12	8.093281
6.		Winter	94.22882	86.9	7.777684	64.7855	59.45	8.235639

5.2 Discussion

Following points represent the discussion made on the basis of Table 5.1, for plate fin arrangement.

a) Comparison of Theoretical and Experimental Tip Temperatures

- **Observations Across Sessions:**
    - The theoretical tip temperatures $T_{tip(th)}$ are consistently higher than the experimental tip temperatures $T_{tip(exp)}$ across all seasons and both sessions.
    - The difference between $T_{tip(th)}$ and $T_{tip(exp)}$ is relatively small, indicating that the theoretical model closely aligns with the experimental results. However, the discrepancy suggests minor heat losses or variations in experimental conditions.
- **Seasonal Trends:**
    - **Summer:** The $T_{tip(exp)}$ is significantly lower than $T_{tip(exp)}$, with the difference being 4.66°C in 2021–2022 and 7.13°C in 2022–2023. This indicates a greater deviation during high-temperature conditions.
    - **Rainy:** The $T_{tip(exp)}$ remains slightly lower than $T_{tip(th)}$, with a consistent difference (around 3.28°C in 2021–2022 and 5.37°C in 2022–2023).
    - **Winter:** The smallest differences are observed in winter, suggesting that the theoretical model is more accurate at lower temperatures.

b) Heat Transfer Rate

- The heat transfer rate shows significant seasonal variation:
    - **Summer:** The highest heat transfer rate values are observed during summer in both sessions, with an increase from 170.64 W in 2021–2022 to 174.19 W in 2022–2023. This suggests that the plate fins perform better at dissipating heat in higher ambient temperatures.
    - **Rainy:** A slight drop in heat transfer rate is observed compared to summer, likely due to increased humidity reducing convective heat transfer efficiency. The values are 155.54 W and 157.12 W for the two sessions.
    - **Winter:** The lowest heat transfer rate values occur in winter (92.44 W in 2021–2022 and 137.36 W in 2022–2023). The lower ambient temperatures likely result in reduced heat dissipation needs.
- **Sessional Variation:**
    - The heat transfer rate improves in the 2022–2023 session compared to 2021–2022 across all seasons, likely due to experimental refinements or improvements in plate fin design.

c) Seasonal Effect on Performance

- The performance of plate fins is season-dependent:
    - **Summer:** High ambient temperatures lead to higher heat transfer rates, demonstrating the effectiveness of the plate fins in extreme conditions.
    - **Rainy:** The intermediate performance suggests that humidity might play a role in moderating heat dissipation.
    - **Winter:** The low heat transfer rates are expected due to reduced temperature gradients between the fins and the environment.

Following points represent the discussion made on the basis of Table 5.2, for pin fin arrangement.

a) Comparison of Theoretical and Experimental Tip Temperatures

- Across all sessions and seasons, the theoretical tip temperatures $T_{tip(th)}$ are higher than the experimental tip temperatures $T_{tip(exp)}$, similar to the plate fin data.
- **Seasonal Trends:**
  - **Summer:** The $T_{tip(th)}$ and $T_{tip(exp)}$ differences are around 4.25°C in 2021–2022 and 5.58°C in 2022–2023. The experimental deviation is higher in 2022–2023, suggesting increased heat losses under higher ambient temperatures.
  - **Rainy:** The difference between theoretical and experimental tip temperatures is consistent and moderate, with differences of 5.21°C (2021–2022) and 5.73°C (2022–2023).
  - **Winter:** The smallest discrepancies occur in winter (4.87°C in 2021–2022 and 5.34°C in 2022–2023), implying better theoretical alignment at lower temperatures.

b) Heat Transfer Rate

- The heat transfer rates are lower for pin fins compared to plate fins, indicating that plate fins dissipate more heat. However, the performance trends are consistent with the seasonal and sessional patterns observed in plate fins.
- **Seasonal Trends:**
  - **Summer:** The highest heat transfer rate values are observed during summer, with an increase from 112.79 W in 2021–2022 to 114.23 W in 2022–2023. Pin fins perform efficiently in higher ambient temperatures due to the increased temperature gradient.
  - **Rainy:** A slight decrease in heat transfer rate is observed during the rainy season (106.47 W in 2021–2022 and 107.07 W in 2022–2023), attributed to the effect of humidity on heat dissipation.
  - **Winter:** The lowest heat transfer rate values occur in winter, with a notable increase from 72.38 W in 2021–2022 to 98.46 W in 2022–2023. This could be due to experimental improvements or material changes in the second session.

c) Sessional Variation

- Across the two sessions, heat transfer rate slightly improves for all seasons in 2022–2023, indicating consistent performance enhancement.
- The theoretical and experimental tip temperatures also show better alignment in the second session, suggesting refinements in the theoretical model or experimental setup.

d) Insights on Theoretical and Experimental Correlation

- Theoretical values slightly over predict the experimental results, as is typical in thermal studies. This over prediction might stem from:
    - Idealized assumptions in the theoretical model (e.g., neglecting heat losses through conduction or radiation).
    - Variability in experimental conditions, such as ambient temperature fluctuations, humidity, and material imperfections.

6. Conclusion, Limitations and Future Scope of the Research

The present section is devoted to the conclusion, limitations and future scope of the research work, the details of which are presented in upcoming sub-sections.

6.1 Conclusion

Following points represent the conclusion of the research work:

- As short fins, the plate fins show tip temperatures better than pin fins;
- As short fins, the plate fins show rates of convective heat transfer better than pin fins; and
- Heat transfer rates are highest in summer due to increased temperature gradients, moderate during the rainy season, and lowest in winter.

6.2 Limitations and Future Scope of the Research Work

The following points represent the limitations of the research work:

- The present research work is limited by investigations on a limited set of properties;
- The research work is also limited to basic experimentations;
- The research is also limited to a period of two session, only; and
- The research work is also limited to a particular type of material, only.

The following points represent the future scope of the research work:

- Improvements in theoretical model by incorporating factors like ambient humidity, fin surface roughness, and radiation losses may be made;
- A detailed research may be called which involve deep experiments in controlled environments to minimize discrepancies;
- Long-term analysis to confirm trends and ensure reliability over time may be carried out; and
- Investigations using advanced materials to enhance thermal conductivity and efficiency in varying seasons may also be made.

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