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Research Article

Selection of longitudinal fin profiles for electronic cooling using Delphi AHP-TOPSIS method

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ABSTRACT

Fins are an important passive means of transferring heat from electronic systems and gadgets. The geometry of fins plays a very important role in their ability to transfer heat. However not much effort has been made in previous studies to select the optimum fin profile for electronic cooling using Multi Criteria Decision Making techniques. Thus in this study, an effort has been made to apply Analytic Hierarchy Process (AHP) with an aim to determine the best longitudinal fin among three different cross sections by satisfying four important conflicting criteria. The decision framework has been constructed by taking help from experts using Delphi technique. Further a sensitivity study has been done to check the robustness of the framework. In four different cases of sensitivity test, the overall ranking of the profiles have been found to be unaltered. As per the opinions received from the experts, the ability to transfer heat has been regarded as the most important criteria by with 51.35 % priority, followed by weight with 28.08 % in the second position. Finally the weights obtained were used in TOPSIS (Technique for order preference by similarity to ideal solution) method to rank the alternatives. While Delphi method fetches important data from experts in the particular field, the AHP converts these linguistic inputs in to numbers and structures the problem hierarchically. Finally TOPSIS method ranks the alternatives based on their closeness from the ideal solutions. In the current work, with a performance index of 0.5867, triangular fin has secured the best rank followed by step (0.5413) and rectangular profiles (0.4155).

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INTRODUCTION

With the increase rate of modernization, there evolves various challenges to meet the needs of the people. Engineering, in this regard helps to optimize the resources, innovating and creating various useful products. However, we often encounter situations where we need to choose the best alternative from a pool of alternatives by determining a number of criterion to meet the desired goal. Here

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comes the use of Multi Criteria Decision Making(MCDM) processes. These techniques have gained a lot of interest to overcome various real life engineering problems in the past few years [1-3]. The MCDM techniques since 1960s, have gained momentum and have contributed to research works in various domains [4,5]. Kumar et al [6] reviewed the MCDM techniques used in the area of sustainable energy development. Abbas and Homayonfar [7] reviewed several mathematical methods used in MCDM techniques from 1999 to 2009. These techniques are developed to categorize alternatives into a limited number of groups and/or rank them based on their performance.

The modern day high end electronic gadgets require the heat to be transferred at a high rate. Fins are the extended surface which serves as a passive means to transfer heat. It finds its use when there is a need to cool down or heat a body where the surface area of the body is not sufficient to meet the desired heat transfer rate. Therefore, the fins help to amplify the surface area that is exposed to the circulating medium. Heat transfer through fins is governed by a few factors, such as the fin geometry, the material they are made of, the properties of the fluid and the temperature gradient between the body and the ambient. Rectangular and triangular fins are the most commonly used geometries, while other shapes like circular, elliptical, and annular fins find their application in specific areas. The choice of fin material is critical as it directly affects the heat transfer ability. Materials such as aluminium, copper and steel are frequently employed for fins. Fluid properties, such as flow rate and temperature, also hold a significant role in determining the ability of fins in facilitating heat transfer. Over the last few decades different variants of fins such as porous and perforated fins [8] have been conceptualized and implemented in various heat exchangers. Thus, designing an efficient finned surface requires a thorough grasp of these influencing factors and their interactions. Liu et al [9] studied a finned foil heat exchanger where the curved shape of the wing structure was difficult to fabricate. Therefore, this study presents a few simple wing designs based on conventional NACA0018 air foil blades to improve the thermal conductivity of PCHE. Mustafa et al [10] designed triangular fins for a forced convection situation. The sandwiched structure of large, small and smallest fins presented an innovative approach for the fin placement. Zhu et al. [11] introduced a fin distribution design resembling a Hanoi tower to enhance the heat storage capacity of a shell-and-tube phase change accumulator. In contrast to traditional annular fin arrangements, the spacing between the fins in this design follows an arithmetic progression, with fin lengths increasing by a fixed ratio. Additionally, the overall

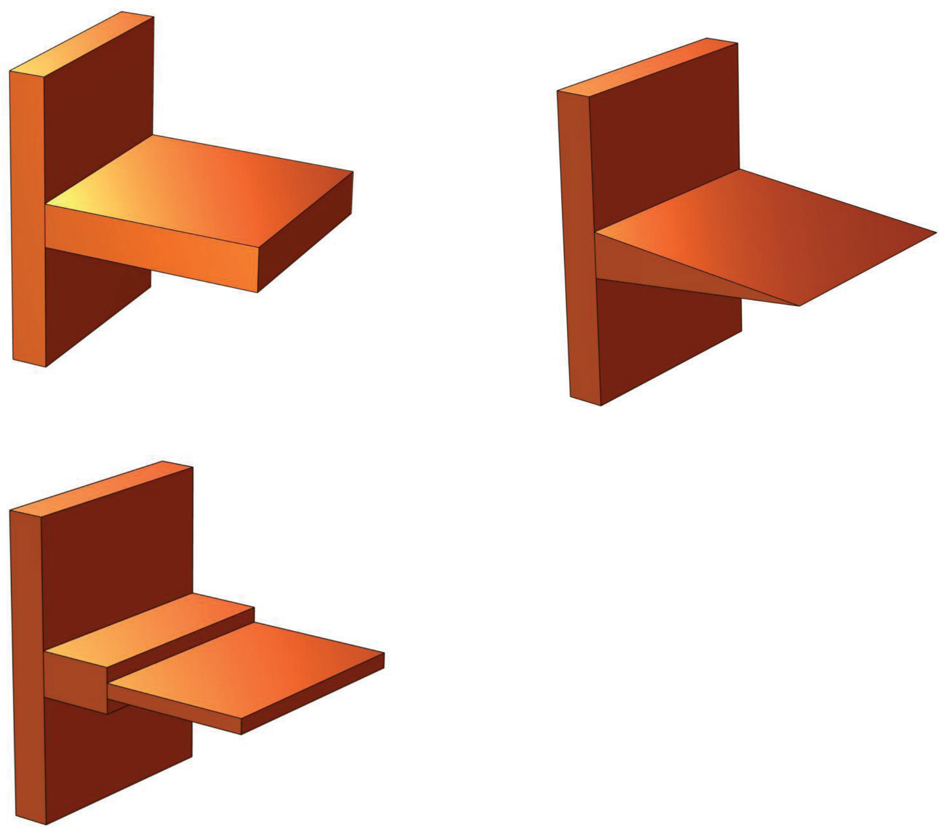

Figure 1. Longitudinal Fins of (a) Rectangular (b) Triangular and (c) Step profiles.

positioning of the fin group adjusts based on the spacing at the bottom. Different cases of fins distributed uniformly and Hanoi-tower shaped distributions were compared with case where no fins are used. Deshamukhya et al [12] carried out a comparative analysis in longitudinal fins in between triangular and stepped profiles. Two powerful swarm intelligence algorithms were used to optimize the key parameters that significantly improve the heat transfer rate. In order to study the effect of fin geometery and number of fins on convection and temperature during phase change in thermal storage unit, Cui et al. [13] studied the thermal performance, thermal storage value, temperature area and total thermal storage over time. The results demonstrate that with an increase with the fin number the temperature of the device rises when the total size of the fins is constant. Moreover, altering the shape of the fin to arc-shape causes the heat storage function to decrease. In another work Hazarika et al [14] performed the heat transfer analysis of an ideal two branched fork-shaped fin array under wet conditions. The obtained results show that heat transfer rate of a rectangular array is less than that of an optimum fork shaped fin array. Zhao et al. [15] observed in their study that the temperature gradient between the inlet and outlet along with total heat storage and heat output increases with an increase in few parameters. But it decreases gradually with higher inlet speed and inlet temperature. They also found that the energy efficiency coefficient of the heat exchanger improves with greater fin thickness and height, while it drops as the surrounding temperature, inlet temperature and inlet speed increases. Jia et al [8] made an effort to examine the effects of fin vents in thermal efficiency in a micro cross-flow heat exchanger. This study shows the relationship between Nusselt number and Reynolds number. Additionally, classifying perforations significantly improves measurement performance compared to perforation images. Finally, the use of fin perforation technology is believed to provide better and more stable power generation for direct methanol production. A comparative study between wavy and spiral fins has been performed by Chimres et al. [16]. They reported that wavy fins produce a higher heat transfer coefficient and greater pressure drop compared to spiral fins (Fig. 1).

In the area of fin design, we often come across a number of conflicting criteria which influences the design of the fin. Over the last few years AHP and TOPSIS methods have been extensively used in different areas of engineering to structure and rank the alternatives. Table 1 summarizes some of the key MCDM studies performed over the last few years in various domains and especially thermal engineering.

From the extensive literature survey, it has been seen that though MCDM techniques have been used in different areas of thermal engineering, but an extensive study of fin geometry have not been conducted so far. The current work finds its novelty in applying Analytical Hierarchy Process and Delphi Method followed by TOPSIS to select the best fin profile suitable for electronic cooling. To the best of authors' knowledge selection and ranking of fin profiles has not been done yet by satisfying multiple conflicting criteria. Four criteria are selected with respect to which the best fin profile is to be selected for electronic cooling application. A rigorous sensitivity analysis has also been performed to check the robustness of the model. This approach can open a new direction of research where MCDM techniques can be used to reach conflicting decisions in the area of fins used in industrial applications.

MATERIALS AND METHODS

In this work, three potential longitudinal profiles have been analyzed and a multicriteria decision making framework has been designed. The aim of this effort is to select the best alternative out of three fin designs which is suitable for electronic cooling. In the first step of the research, Delphi method has been used where three experts were chosen based on their expertise in the area of thermal engineering. The data obtained from the Delphi method was used to carry out the pair wise comparison among the criteria and the alternatives. The weights obtained by AHP were used to rank the alternatives by TOPSIS method. A sensitivity analysis has also been done to check the consistency of the framework.

Delphi Method

The Delphi method [32] uses the expertise of a panel of experts in a particular field. It is commonly utilized in research, particularly in multi-criteria decision-making contexts, where a diverse range of perspectives is valuable. The process typically involves several rounds of questionnaires or surveys, where experts anonymously provide their opinions, feedback, and potential solutions to a specific problem or set of criteria. After each round, the responses are aggregated and summarized, and then presented back to the experts for further consideration and refinement. This iterative process will continue till we get a consensus or convergence of opinions among the experts. The anonymity of the Delphi method encourages honest and unbiased responses, while the iterative nature allows for the exploration of complex issues and the refinement of solutions over time. As a result, the Delphi method is widely regarded for its effectiveness in generating reliable and informed decisions, particularly in situations where there is uncertainty or disagreement among experts (Fig. 2).

In this study the main aim behind using Delphi method is to form the pair wise comparison table by taking feedback from experts. Three experts were chosen based on their experience in the area of thermal engineering research, especially fins. The details of the experts are presented in Table 2. A detailed questionnaire covering all the important parameters have been prepared by the authors and sent to the experts. The questions covered different areas of fin design such as geometrical aspects, cost and

Table 1. Application of AHP and TOPSIS in various Engineering analysis

Sl. No.	Authors	Objective of the work	Method	Inference
1.	Sabharwall et al [17]	To identify the main alternatives and criteria necessary for the secondary heat exchangers (SHXs)	AHP	Among two different heat exchanger configurations, the shell-and-tube heat exchanger with helical coils has been chosen for the reactor due to its superior reliability.
2.	Ravello et al [18]	To improve a shell and tube heat exchanger's efficiency by considering three main criteria and nine sub criteria.	AHP	Proposed a strategy to enhance a heat exchanger's efficiency operating under real conditions by implementing innovative online cleaning systems.
3.	Kibria et al.[19]	To evaluate priorities for managing cultural resources at Cape Lookout National Seashore in response to climate change.	AHP	They used AHP to facilitate discussions with stakeholders in order to maximize four important parameters. The main goal however was to maximize HCC, by providing equal priority to HA and FB.
4.	Diriba et al [20]	To identify some zones which are suitable for groundwater within the Main Ethiopian Rift using the AHP method to assign weights to various factors.	GIS, RS and AHP	Eight groundwater regulating factors were analyzed, with AHP assigning suitable weights to each factor. The GWPZ was classified into five categories. The study suggests that water policymakers should give importance to develop groundwater resources in favorable GWPZs to improve both agriculture and domestic water supply.
5.	Ahadi et al [21]	To select a regionally optimal site for solar power plants by selecting seven crucial criteria.	AHP	Out of many provincial centers, the study selected Zahedan as the most favourable location for installing a solar power plant.
6.	Mohsen[22]	To select a freight forwarder using AHP to assess various factors, including service quality, specialized services, information & technology.	AHP	The study identifies specialized service as the most crucial criterion, followed by service quality, competitive pricing, information and technology, network, and sustainability.
7.	Okudan and Budayan[23]	To determine the features of construction projects that significantly contribute to the occurrence of risks.	Fuzzy AHP	Few factors that are most important in risk occurrence cases are contract related characteristics, contract type and project value.
8.	Ayvaz et al. [24]	To select appropriate supplier under uncertain environment.	Fuzzy TOPSIS	A supplier selection scheme is presented using fuzzy TOPSIS.
9.	Öztekin and Cüce [25]	To determine appropriate fin material	AHP	A standard decision making scheme has been presented to select the optimal fin profile.
10.	Sun et al. [26]	To identify an optimal compromise solution from a set of Pareto solutions to create an intelligent design system for plate fin-and-tube heat exchangers (PFTHE).	ANN-TOPSIS	An optimal compromise solution has been achieved by a method by reducing the tube bundle's pressure drop by 80% while maintaining adequate heat transfer performance.
11.	Mostafa and Hebel [27]	Introduced a closeness coefficient to rank alternatives networks based on how far the alternatives are from the ideal solution.	TOPSIS	They considered two case studies to illustrate efficacy in dealing discrete multicriteria decision making problems.
12.	Sethuraman [28]	To analyze a copper heat pipe for waste heat recovery.	TOPSIS	The optimized condition was attained in the 19th from the TOPSIS results
13.	Adhyaru et al. [29]	To optimize of pin fin heat sink's performance by reducing the heat source's maximum temperature	ANOVA, TOPSIS and Taguchi	Compared different types of pin fin heat sinks to understand their performance under various conditions.
14.	Zübeyr et al. [30]	To choose the most appropriate province		Production-distribution network system of a bottling company has been analyzed.
15.	Yilmaz et al [31]	To identify the priority areas in the meter replacement or rehabilitation	AHP and ELECTRE I	Making substantial progress in minimizing losses caused by meters, lowering meter management costs, and maximizing benefits in meter replacement.
16.	Şenyiğit and Demirel [40]	To select the best packaging material for soft drinks by taking in to account 17 alternative materials.	AHP, TOPSIS and SAW	By considering seven different criteria, a scheme has been formulated to use MCDM techniques in material selection process.

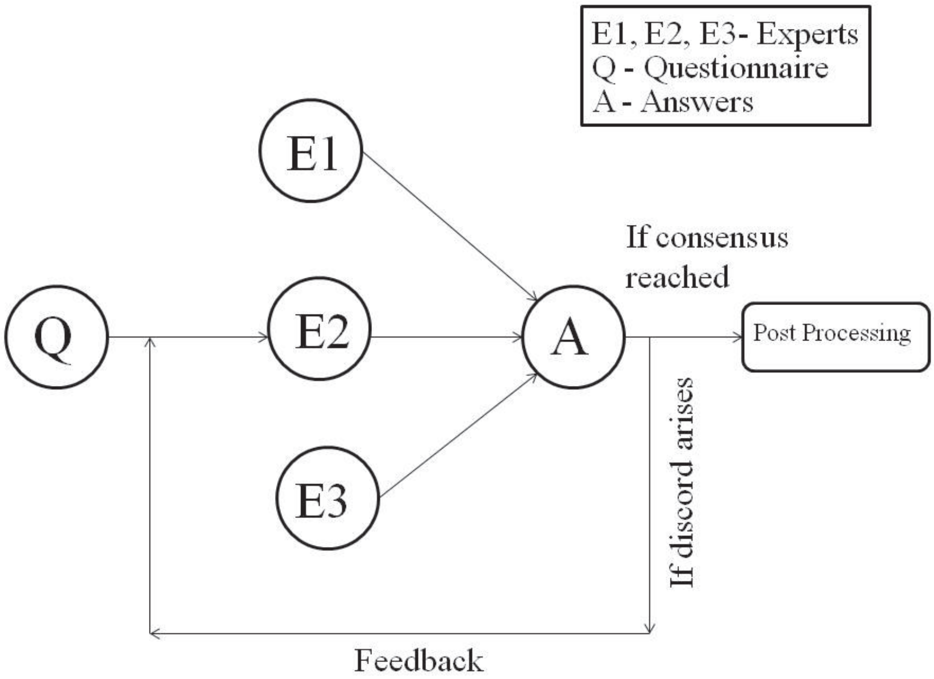

Figure 2. Information flow in Delphi method.

material saving, heat transfer ability and so on. For every question, the experts were asked to tick an option out of multiple options (such as 'very important, 'moderate', 'insignificant' etc). After the answers were obtained and analyzed, consensus was reached in most of the questions while on two questions, the answers were found to vary. In the second round the feedback was sent back to the experts for their opinion and finally consensus has been reached. This laid the foundation for the decision framework of AHP.

THE MCDM FRAMEWORK

A typical MCDM scheme mainly needs four basic components for its implementation. They can be briefed as:

i) Alternatives – Goal of any MCDM problem is to rank and discover the best alternative from a group of alternatives.

ii) Criteria- The alternatives are evaluated and compared for most applications. The number of criteria in a problem depends on the problem at hand.

iii) Weight- It represents the relative importance of each criteria and the alternatives. There are various techniques available to determine the weightage of the criteria.

iv) Decision Makers and other stakeholders- Perhaps the most important element of the decision framework system, the views expressed by the decision makers highly influence the output of the decision. Decision makers (experts) involved may range from just one up to as many as 100s of people.

Analytic Hierarchy Process

Developed by Saaty [33,34] AHP i.e, Analytic Hierarchy Process is an MCDM tool that helps in analyzing complicated decisions from a pool of options or alternatives. In the first phase of the study, the basic structure of the problem is formed and experts are chosen for Delphi method. A set of questionnaire is sent to the experts and the inputs are recorded. Once the consensus is reached, in the second phase, the linguistic opinions of the experts are converted to mathematical values using pair wise comparison table (Table 2) [34]. The process of AHP starts from this step. The consistency of the weights in the matrix is then checked by evaluating the consistency ratio (CR) as explained in section 4.2. If the matrix is found to be consistent, the global weightages of the alternatives are computed. Finally in order to check the robustness of the decision support system, a sensitivity analysis has been done (Fig. 3).

The decision framework of AHP has been created based on a number of conflicting factors which have been discussed below. The criteria (C1 to C4) considered to be crucial in obtaining the optimum fin profile in this study have been selected based on experts' opinions. Now regarding the weightage distribution in table 4, the criteria 'heat transfer ability (C1)', for example, was given the maximum weightage by all the experts unanimously. Thus based on these linguistic opinions, C1 has been allotted a higher numerical value (from table 1) by comparing with remaining criteria. The weights of other criteria have been allotted with respect to each other in the similar fashion.

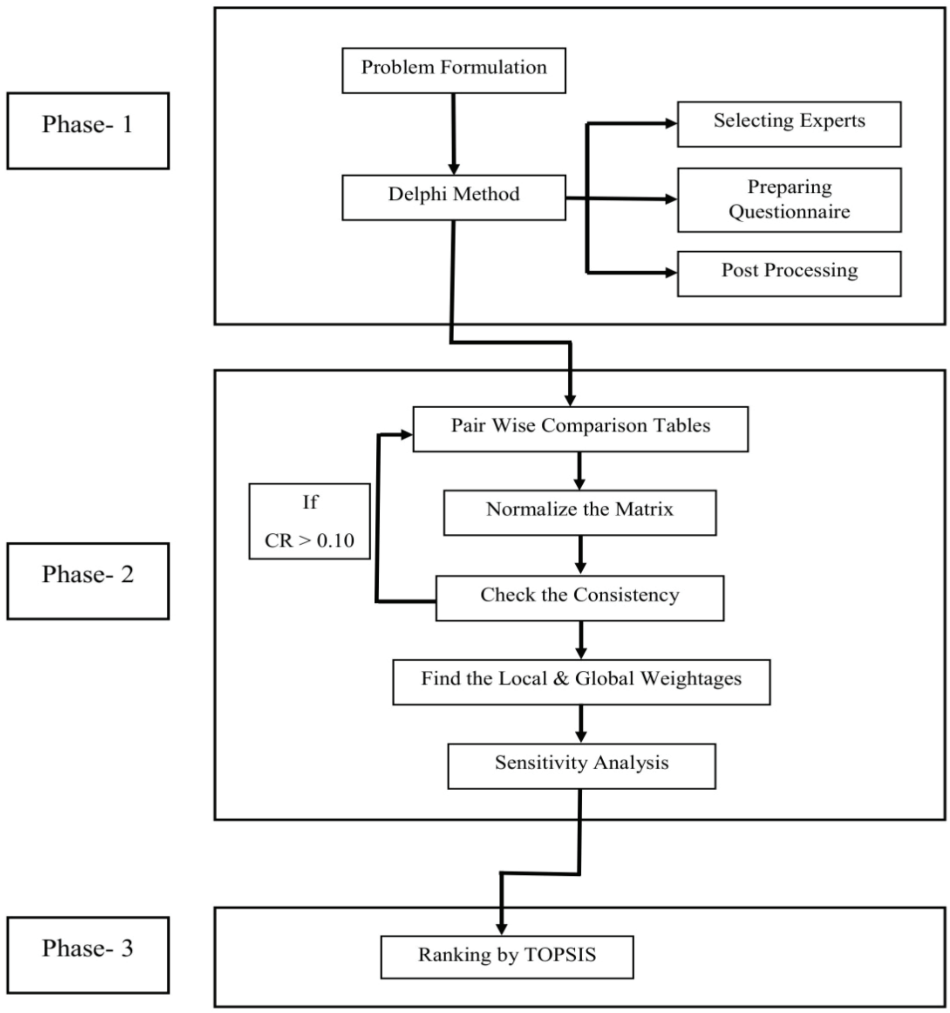

Figure 3. Process flow of delphi- AHP- TOPSIS technique.

Table 2. Saaty's 9 point scale [34] [created by author]

Intensity of importance	Definition
1	Equal importance
3	Moderate important
5	Much more important
7	Very much more important
9	Absolute more important
2,4,6,8	Intermediate values

i) Heat Transfer Ability (C_1): Since the primary goal of using fins is to improve the heat transfer rate, so this is perhaps the most important of all the criteria.

ii) Material Saving (C_2): This is another important criteria in designing any engineering equipment since optimized use of material not only reduces the weight of the assembly, but also translates in profit by reducing the cost

iii) Weight (C_3): Weight is an important factor in deciding components for electronic cooling. So fins with less weight

iv) Ease of Manufacturing (C_4): Along with the above criteria, ease of manufacturing is also an important factor, since profiles which are difficult to fabricate or require advanced manufacturing processes will again increase the cost.

The above criteria have been evaluated with respect to three fin profiles of longitudinal cross section. These serves as the alternatives in our study.

i) Rectangular Profile (A_1): One of the most common profiles used across industries, the rectangular fn profile is known for its seemingly straightforward mode of manufacturing.

ii) Triangular profile (A_2): The thickness of triangular fins decreases gradually from the base to the tip, thereby reducing the weight and material usage.

iii) Step profile (A_3): Reducing the fin in step is an innovative way to reduce weight and save material by removing material near the end of the fin.

Here it is worth mentioning that the tip of the fin does not contribute much in heat transfer. This is because heat transfer by convection is directly dependent on the gradient of temperature between the body of the fin and the ambient. And as we move away from the base toward the end, the surface temperature drops continuously. Since the heat transfer from the end part of the fin is less, so in step and triangular profiles, material is removed from these regions.

TOPSIS METHOD

TOPSIS (Technique for order preference by similarity to ideal solution) method [35,36] is based on the idea that the best solution has the shortest distance from the positive ideal solution. The problem consists of a set of alternatives, A_i (i = 1, 2, …,) based on certain criteria C_j (j = 1, 2, … , J). The technique follows the following steps:

Step 1: Normalization of the matrix

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{1J} \\ x_{21} & x_{22} & x_{2J} \\ x_{I1} & x_{I2} & x_{IJ} \end{bmatrix} \quad (1)$$

The above matrix is normalized to make the comparison easier with dimensionless attributes using the following rule:

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (2)$$

Each element of the matrix is divided by its norm.

$$Y = \begin{bmatrix} y_{11} & y_{12} & y_{1J} \\ y_{21} & y_{22} & y_{2J} \\ y_{I1} & y_{I2} & y_{IJ} \end{bmatrix} \quad (3)$$

The weights obtained from AHP are now integrated with the normalized decision matrix. Thus we get the weighted normalized decision matrix.

$$v_{ij} = w_j y_{ij},\ where\ i = 1,2,...,I;\ j = 1,2,...,J$$

$$V = \begin{bmatrix} v_{11} & v_{12} & v_{1J} \\ v_{21} & v_{22} & v_{2J} \\ v_{I1} & v_{I2} & v_{IJ} \end{bmatrix} \quad (4)$$

Step 2: Finding the ideal Solutions

The next step is to calculate the ideal solutions V_j^+ and V_j^-, where V_j^+ denotes the best possible value, V_j^- denotes the worst value. For beneficial criterion, V_j^+ corresponds to the maximum value of the column whereas V_j^- refers to the particular column's minimum value. For non-beneficial criterion, it is vice versa.

$$V_j^+ = \begin{vmatrix} \max v_{ij}, if\ j\ is\ beneficial\ criteria \\ \min v_{ij}, if\ j\ is\ non\text{-}beneficial\ criteria \end{vmatrix}$$
$$V_j^- = \begin{vmatrix} \min v_{ij}, if\ j\ is\ beneficial\ criteria \\ \max v_{ij}, if\ j\ is\ non\text{-}beneficial\ criteria \end{vmatrix} \quad (5)$$

Step 3 Calculation of Euclidean Distance

Now it is essential to calculate the Euclidean distance of the obtained solutions from their ideal best and ideal worst values. S_j^+ refers to the distance of the values from the ideal best solutions and S_j^+ refers to the distance of the values from the ideal worst solutions. S_j^+ and S_j^- values have been computed in the table.

$$S_i^+ = \sqrt{\sum_{j=1}^{J} (v_{ij} - V_j^+)^2} \quad (6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{J} (v_{ij} - V_j^-)^2}$$

Finally the performance index (PI) is calculated as:

$$PI = \frac{S_i^-}{S_i^- + S_i^+} \quad (7)$$

RESULTS AND DISCUSSION

In the present study, three fin profiles have been studied using AHP and TOPSIS to select the best fin profile for electronic cooling by analyzing four essential criteria. Since the decisions obtained from AHP depends highly on the feedback obtained from the decision maker, so an effort has been made to select four experts who have requisite expertise in the area of thermal engineering and especially fins. Details of the experts are given in Table 3. A Delphi framework has been adopted and the questionnaires were sent to the experts. Now based on the suggestions obtained from them, the weightages are given to each criterion and alternatives for pair wise comparison.

Table 3. Details of experts who participated in this study

	Experience (in years)	Institution
Expert 1	14	National Institute of Technology Silchar
Expert 2	17	National Institute of Technology Silchar
Expert 3	11	Institute of Infrastructure, Technology, Research And Management, Ahmedabad
Expert 4	12	National Institute of Technology Mizoram

Delphi-AHP Analysis

The analysis begins with the criteria's pair wise comparison with each other as seen in Table 4. For converting the linguistic opinions of the experts, Satty's 9 point scale (Table 1) has been used.

Now to bring the comparison in a common scale, the values are normalized in the range of [0,1] as shown in Table 5. The criteria weights of each of the criterion have been determined by adding all the normalized values of each row. The weights thus obtained have to be checked for consistency.

Checking the consistency of the matrix

To ensure that the pair wise comparison matrix formed by taking judgments from the experts are consistent and logical, a consistency check [23] has to be performed. The process begins with checking the consistency index, CI.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{8}$$

where in order to calculate λ_{max} we need to take the average of the column which contains the ratio of weighted sum value and the criteria weights

Here 'n' is the total number of criteria

The consistency ratio, CR can be found out by $CR = \frac{CI}{RI}$

Where RI is a random number index. It depends on the number of criteria of the problem. RI value can be found out from Table 6 [37].

Now to get a consistent pair wise matrix, CR value should be less than 10%. In case the CR is higher, the matrix has to be recalculated. Here it is worth mentioning that the priority of the criteria has been calculated in table 4. Table 7 shows the consistency check calculations of the normalized decision matrix.

Once it has been ensured that the criteria matrix is consistent, the weightages of alternatives can now be determined in the similar way. For each criterion, the alternatives are evaluated in a pair wise comparison matrix with respect to each other. This gives an idea about the relative importance of the alternatives with respect to each criterion. In Table 8, the alternatives are evaluated with respect to the criteria and the pair wise comparison matrices is shown. Here the experts have unanimously suggested the heat transfer ability of the triangular fins to be the best among the three alternatives. Similar outcome was reported by Ali

Table 4. Pairwise comparison of the criteria

	C1	C2	C3	C4
C1	1	4	3	5
C2	0.25	1	0.33	3
C3	0.33	3	1	5
C4	0.2	0.33	0.2	1
Σ	1.78	8.33	4.53	14

Table 5. Normalized decision matrix

	C1	C2	C3	C4	Criteria weight
C1	0.561798	0.480192	0.662252	0.357143	0.515346
C2	0.140449	0.120048	0.072848	0.214286	0.136908
C3	0.185393	0.360144	0.220751	0.357143	0.280858
C4	0.11236	0.039616	0.04415	0.071429	0.066889

Table 6. Values of random number index

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

et al. [38] in their experimental work on heat sinks with triangular and rectangular pin fins in electronic circuits with phase change materials.

The criteria weights obtained from each table will be used to calculate the overall weight of the alternatives. In the final step, all the weightages obtained so far has been computed in Table 9 to get the global priority values of the three alternatives. Alternative A2 (Triangular Fin) has secured the highest weightage of 56.73% followed by step fin with 29.93% and rectangular fin with 13.33%.

Post Selection Sensitivity Analysis

The expert opinions form the basis of pair wise comparison of the decision matrix. Since the final priorities of the alternatives are highly influenced by the opinion from experts, it becomes necessary to check the accuracy of the weightages provided to the criteria. Dey et al. [39] performed a single dimensional sensitivity analysis of their decision framework by varying the criteria weight of the best criteria uniformly. In this section three different cases are studied where the weights of the criteria have been varied to check their influence on the overall ranking of the alternatives. Details of this variation can be seen in Table 10. Here Case 1 refers to the original weights of the criteria and the respective ranking of the alternative. In Case 2, all the criteria have been given equal weightage. As a result though the global priority values of the alternatives changes to A1 =0.2357, A2= 0.5046 and A3= 0.2597, A2 still retains the best rank. In Case 3 and Case 4 the weightages are distributed randomly to all the criteria. Corresponding values

Table 7. Consistency check of the criterion matrix

	C1	C2	C3	C4	Weighted Sum	CW	Ratio
C1	0.51535	0.54764	0.84258	0.33445	2.24002	0.51535	4.346599
C2	0.128837	0.13691	0.092684	0.20067	0.559101	0.13691	4.083714
C3	0.170066	0.41073	0.28086	0.33445	1.196106	0.28086	4.258725
C4	0.10307	0.04518	0.056172	0.06689	0.271312	0.06689	4.056097
						Σ	16.74514
	CI=	0.062095				λ_{max}	4.186284
	RI=	0.9					
	CR=	0.068994					

Table 8. Pair wise comparison of the alternatives

C1	A1	A2	A3	Criteria Weight	C2	A1	A2	A3	Criteria Weight
A1	1	0.2	0.25	0.09819	A1	1	0.2	0.33	0.109286
A2	5	1	2	0.567873	A2	5	1	2	0.581464
A3	4	0.5	1	0.333937	A3	3	0.5	1	0.30925
	CI=0.01232	*RI=0.58*	*CR=0.0212*			*CI=0.0002*	*RI=0.58*	*CR=0.0004*	
C3	**A1**	**A2**	**A3**	**Criteria Weight**	**C4**	**A1**	**A2**	**A3**	**Criteria Weight**
A1	1	0.166	0.25	0.086898	A1	1	3	5	0.64842
A2	6	1	3	0.639929	A2	0.33	1	2	0.2293
A3	4	0.33	1	0.273173	A3	0.2	0.5	1	0.1223
	CI=0.0248	*RI=0.58*	*CR=0.0428*			*CI=0.0002*	*RI=0.58*	*CR=0.0004*	

Table 9. Global priority and rank of the alternatives

	C1(0.51535)	C2(0.13691)	C3(0.28086)	C4 (0.06689)	Global Priority
A1	0.09819	0.109286	0.086898	0.64842	0.1333
A2	0.567873	0.581464	0.639929	0.2293	**0.5673**
A3	0.333937	0.30925	0.273173	0.1223	0.2993

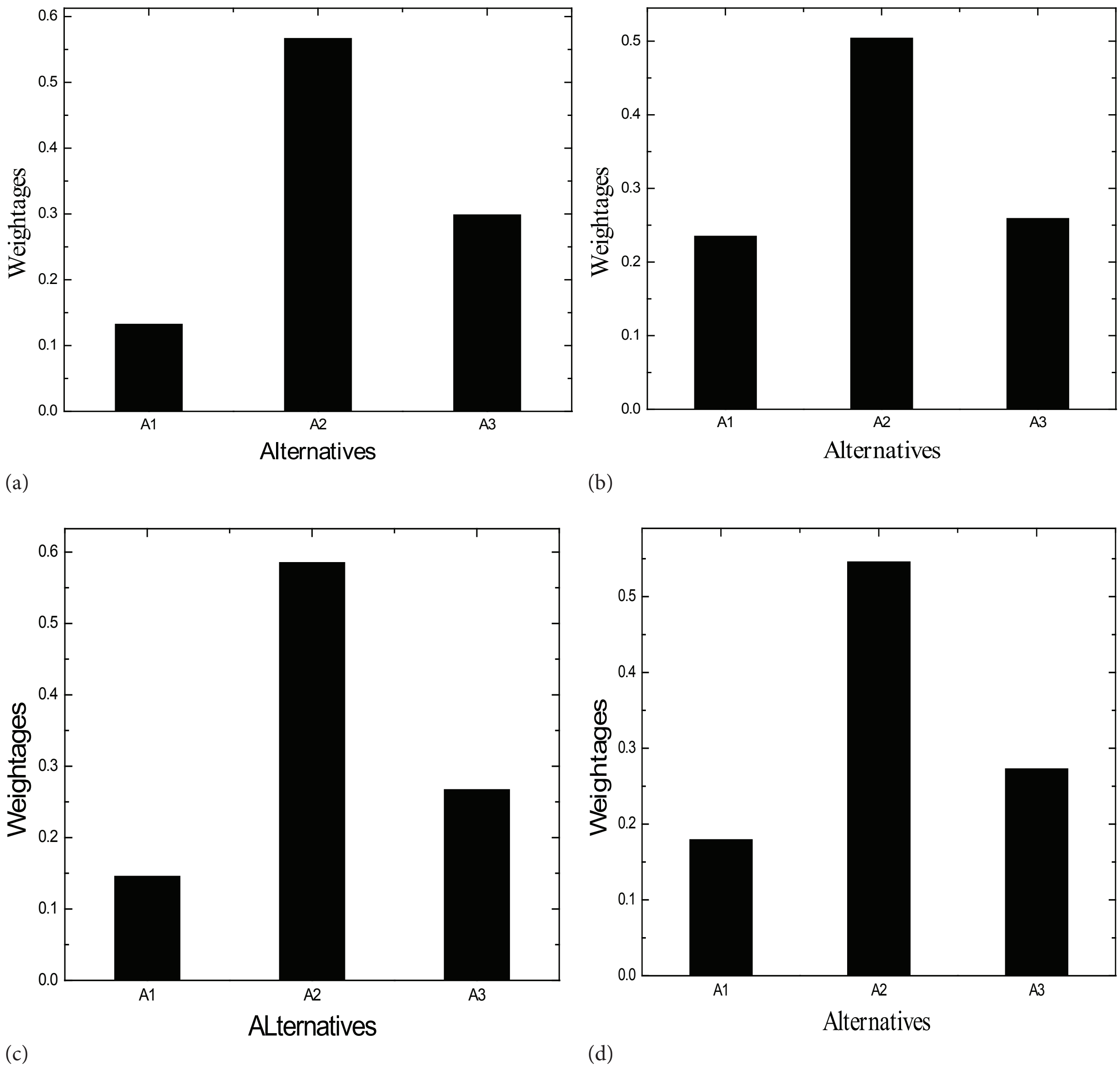

Figure 4. Overall weights of the alternatives for (a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4.

Table 10. Results of sensitivity analysis

	C1	C2	C3	C4	Result
Case 1	**0.5154**	0.1369	0.2809	0.0669	A2>A3>A1
Case 2	0.2500	0.2500	0.2500	0.2500	A2>A3>A1
Case 3	0.1000	0.1000	**0.7000**	0.1000	A2>A3>A1
Case 4	0.2000	0.3000	**0.3500**	0.1500	A2>A3>A1

of the alternatives obtained are (A1 = 0.1464 , A2= 0.5858 and A3= 0.2678) and (A1= 0.1801, A2= 0.5464 and A3=0.2735) for case 3 and case 4 respectively. An interesting observation of this sensitivity analysis is that Alternative A2 has managed to secure the best rank in all the four cases. Moreover the trend seen in all the cases (A2>A3>A1) is same. This testifies the robustness of the decision framework (Fig. 4).

TOPSIS

The normalized decision matrix obtained from AHP (Table 9) has been used to calculate the ideal solutions. This matrix is converted to weighted normalized decision matrix in Table 11 by multiplying the weights (C1-0.51535, C2- 0.13691, C3-0.28086, C4-0.06689) obtained from AHP using the equation (4). In table 11, the values of ideal best and ideal worst solutions are computed which has been calculated using equation (5). For beneficial criteria the maximum value of the corresponding columns will be the ideal best V_j^+ and the minimum value will be ideal worst V_j^-.And for non-beneficial criteria, this is vice versa. Following this the Euclidean distance of the solutions from their ideal best (S_j^+) and ideal worst (S_j^-) is calculated using equation (6) in Table 12.

In Table 13, the final performance index is calculated following the rules of equation (7). The alternative which gets the highest value is considered as the best of all the available options. Here A2, i.e., fins of triangular profiles is found to be best satisfying the above 3 criterion (Fig 5).

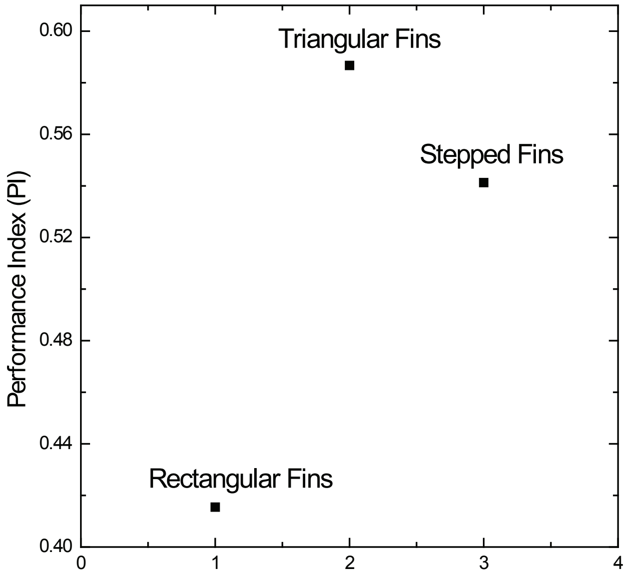

Figure 5. Performance Index of the alternatives.

Table 11. Weighted normalized decision matrix

	Beneficial	Non-Beneficial	Non-Beneficial	Beneficial
	C1(0.51535)	**C2(0.13691)**	**C3(0.28086)**	**C4 (0.06689)**
A1	0.05060222	0.01496	0.024	0.043
A2	0.29265335	0.07961	0.18	0.015
A3	0.17209443	0.04234	0.077	0.008

Table 12. Calculation of Euclidean distance from the ideal best and ideal worst solution

	Beneficial	Non-Beneficial	Non-Beneficial	Beneficial	S_j^+	S_j^-
	C1(0.51535)	**C2(0.13691)**	**C3(0.28086)**	**C4 (0.06689)**		
A1	0.05060222	0.01496	0.024	0.043	0.2421	0.1721
A2	0.29265335	0.07961	0.18	0.015	0.1705	0.2421
A3	0.17209443	0.04234	0.077	0.008	0.1387	0.1637
V_j^+	0.2926	0.0149	0.0244	0.0433		
V_j^-	0.0506	0.0797	0.18	0.008		

Table 13. Calculation of performance index (PI)

	S_j^+	S_j^-	$S_j^+ + S_j^-$	**Performance Index (PI)**
A1	0.2421	0.1721	0.4142	0.4155
A2	0.1705	0.2421	0.4126	**0.5867**
A3	0.1387	0.1637	0.3024	0.5413

CONCLUSION

In the previous studies related to fins, no work has been done to select the best fin profile by satisfying conflicting criteria using multi criteria decision techniques. Thus in this novel study three different fin profiles have been analyzed using Delphi-Analytic Hierarchy Method and Technique For Order Preference By Similarity to Ideal Solution framework. The aim is to select the best profile by evaluating four important criteria. The Delphi scheme has been adopted to fetch opinions from experts in the area of thermal engineering. These linguistic opinions have been converted using a 9 point scale to form the pairwise matrix. The result of the framework suggested that longitudinal fin of triangular cross section is optimum for electronic cooling applications. Once the global priority values of the alternatives have been obtained, an extensive sensitivity analysis have been performed to check the robustness of the framework. Following noteworthy conclusions can be drawn:

i) Triangular fins have secured the best rank by satisfying four different criteria involved in this study followed by step and rectangular profiles. This result can be credited to the linearly tapering structure of the fin. Convective heat transfer through fin is directly proportional to the temperature difference between the fin body and the surrounding. So as we move toward the tip, the body temperature drops which reduces the temperature difference. Thus the later part of a fin near the tip does not take part significantly in transferring heat. So in triangular fins material near the tip is removed which not only saves material (which in turn translates to cost reduction) but also reduces the weight of the assembly.

ii) After the ranking is done, a sensitivity analysis has been performed to check the robustness of the framework. The weightages of the criteria were varied and the global priorities of the alternatives were determined for three different cases. As compared to Case 1 (original values), in Case 2, A1 increases by 76.81%, A2 decreases by 11.054% and A3 decreases by -13.23% while in Case 3, A1 and A2 increases by 9.82% and 3.26% and A3 decreases by 10.52%. Finally in Case 4, A1 increases by 35.10% while A2 and A3 decreases by 3.68% and 8.62% respectively. These changes in the global weightages are due to the change in criteria weights. However in all the cases triangular fin (A2) has secured the best rank followed by Step(A3) and Rectangular(A1) profiles. The unaltered trend in all these cases gives an indication that the decision framework is robust.

iii) Among the conflicting criteria in fin design, the ability to transfer heat has been regarded as the most important criteria by the experts with 51.35 % priority, followed by weight with 28.08 % in the second position.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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APPENDIX

Sample Calculation

A sample calculation of TOPSIS method has been shown for the *alternative A3*.

Step 1: Formation of weighted normalized decision matrix

The weights obtained from AHP (table 8) are integrated with the normalized decision matrix. Thus we get the weighted normalized decision matrix in table 11.

$$v_{ij} = w_j y_{ij},\ where\ i = 1,2,\ldots,I;\ j = 1,2,\ldots,J$$

$$0.1720944 = (0.51535) \times (0.339)$$

In the similar manner, the remaining values of the table 12 have been obtained.

Step 2: Calculation of V_j^+

Now in the first column, which is a beneficial criteria, $V_j^+ = 0.2926$ is the maximum value of the column. Similarly $V_j^- = 0.0506$ is the minimum value of the first column. For non-beneficial criterion C2 and C3, it is vice versa.

Step 3: Calculation of distance from ideal solutions

S_j^+ refers to the distance of the values from the ideal best solutions and S_j^+ refers to the distance of the values from the ideal worst solutions. S_j^+ and S_j^- values have been computed in the table.

$$S_i^+ = \sqrt{\sum_{j=1}^{J}(v_{ij} - V_j^+)^2} = \sqrt{(0.1720944 - 0.292653351)^2 + (0.04234 - 0.014962346)^2 + (0.024406 - 0.18)^2 + (0.043373 - 0.008)^2} = 0.13877$$

$$S_i^- = \sqrt{\sum_{j=1}^{J}(v_{ij} - V_j^-)^2} = \sqrt{(0.17209443 - 0.0506)^2 + (0.04234 - 0.07961)^2 + (0.024406 - 0.18)^2 + (0.043373 - 0.008)^2} = 0.16376$$

Step 4: Calculation of the performance index (PI) in Table 13

$$PI = \frac{S_i^-}{S_i^- + S_i^+} = \frac{0.1637}{0.16376 + 0.13877} = 0.54134$$