

Design and Performance Enhancement of Industrial Air-Cooling Units Using CAD–FEA Based Optimization

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ABSTRACT

Industrial air-cooling units (ACUs) are essential components in cold storage, food processing, and industrial refrigeration facilities. However, many commercially used ACUs still rely on conventional sheet-metal designs that exhibit structural weakness, excessive vibration, non-uniform airflow, and inefficient defrosting. These issues lead to reduced cooling efficiency, frequent maintenance, and shortened equipment life. This study presents a computer-aided design (CAD) and finite element analysis (FEA)–based framework for improving the mechanical and thermal performance of an industrial air-cooling unit developed at Star Coolers and Condensers Pvt. Ltd., Jalgaon, India. The proposed approach integrates field observations, geometric redesign, structural and modal analysis, and computational fluid dynamics to identify and eliminate key design deficiencies such as fan -plate cracking, vibration amplification, poor rigidity, and uneven defrost water distribution. Simulation-based evaluation shows that targeted geometric modifications can significantly enhance structural stability, airflow uniformity, and operational reliability without increasing manufacturing complexity. The study demonstrates that CAD–FEA driven design optimization provides a practical and cost-effective route for modernizing industrial ACUs under Indian operating conditions.

Keywords: Air-Cooling Unit, Finite Element Analysis, CFD, Refrigeration Systems, Structural Optimization, CAD

1. INTRODUCTION

Air-cooling units are widely used in industrial refrigeration systems to extract heat from cold rooms and controlled environments. In such systems, the ACU functions as an evaporator where refrigerant absorbs heat from the circulating air through fin-tube heat exchangers assisted by axial fans. The overall cooling performance therefore depends not only on the refrigeration cycle but also on the mechanical integrity and airflow distribution of the ACU structure.

Despite their importance, many industrial ACUs are still manufactured using legacy designs that were developed years ago and have not been systematically optimized for present-day operating conditions. In Indian industrial environments, high ambient temperatures, continuous operation, humidity, and dust further intensify problems such as vibration, structural fatigue, non-uniform airflow, and ineffective defrosting. These issues result in uneven coil icing, reduced heat transfer, increased power consumption, and premature component failure.

Modern engineering tools such as CAD modeling, finite element analysis, and computational fluid dynamics offer powerful capabilities to analyze and improve such systems. When applied in an integrated manner, these tools allow engineers to predict stress, vibration, temperature distribution, and airflow behavior before physical prototypes are manufactured. This research applies these tools to redesign and enhance an industrial air-cooling unit for improved performance and reliability.

2. MANUFACTURING AND TESTING OF AIR-COOLING UNITS

2.1 Manufacturing Process

The development of an air-cooling unit starts with the estimation of cooling load and the volume of space to be conditioned. These parameters determine the size of the heat exchanger, number of fans, motor capacity, and overall geometry of the unit. Based on these design inputs, sheet-metal components such as end plates, drain trays, fan housings, and structural supports are created. These parts are fabricated through cutting, bending, and welding operations and then assembled into the final ACU structure.

Although this process is well established, the geometric configuration is often inherited from older designs. Without systematic analysis, such designs may suffer from weak load paths, excessive vibration transmission, and inefficient airflow distribution.

2.2 Simulation and Numerical Testing

To overcome these limitations, numerical simulations are employed to evaluate the performance of the ACU. Structural analysis is used to assess stresses and deformations caused by fan loads, self-weight, and mounting conditions. Thermal analysis helps in understanding temperature distribution and heat transfer across the coil and housing. Modal analysis is conducted to determine natural frequencies and vibration behavior of the fan-motor assembly and sheet-metal structure. Computational fluid dynamics is applied to examine airflow patterns, pressure drop, and distribution across the finned coil.

Together, these tools enable virtual testing of the ACU, allowing weak regions and performance bottlenecks to be identified before physical fabrication.

3. RESEARCH GAP

Star Coolers and Condensers Pvt. Ltd. manufactures industrial ACUs using heat exchanger and housing designs that originate from earlier foreign designs. While these designs were suitable for their original environments, they do not fully match Indian climatic and operating conditions. Previous attempts to improve performance by adjusting only a few parameters have not produced satisfactory results.

This highlights the lack of a comprehensive design-optimization framework that simultaneously considers structural strength, vibration, airflow, and thermal performance. A holistic, simulation-based approach is required to redesign ACUs for higher reliability and efficiency under Indian industrial conditions.

4. PROBLEM STATEMENT

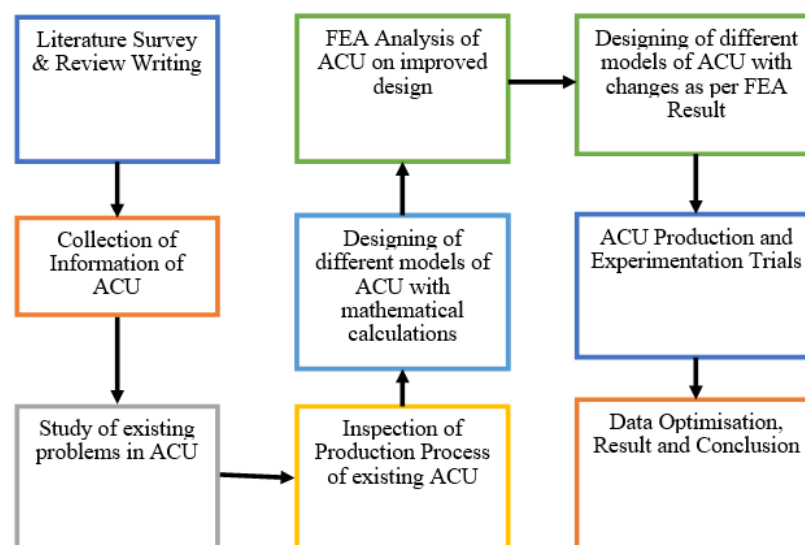
The existing ACU models suffer from several operational problems, including cracking of fan plates, vibration of fan-motor assemblies, weak sheet-metal rigidity, and non-uniform defrosting of the coil. Since these units are suspended from ceilings using hangers, vibration and insufficient stiffness lead to fatigue damage and noise.

The objective of this research is to redesign the ACU structure and airflow path using CAD and FEA tools so that mechanical strength, vibration behavior, and cooling performance are simultaneously improved while maintaining manufacturability.

5. REVIEW OF RELATED WORK

Earlier studies in mechanical and thermal system design have demonstrated that finite element analysis and experimental validation can significantly improve structural reliability and performance. Research in CAD–CAE integration, vibration analysis, and thermal optimization has shown that numerical simulation reduces development time and material waste while increasing product reliability. However, only limited studies have focused on the integrated optimization of industrial air-cooling units, especially under Indian climatic and industrial conditions.

6. RESEARCH METHODOLOGY



7. CURRENT PROGRESS

The research has completed literature review, market survey, and inspection of industrial ACUs at Star Coolers and Condensers Pvt. Ltd. Key issues such as fan-plate cracking, vibration transmission, poor rigidity, and uneven defrosting have been documented. CAD models of the existing and modified ACUs are under development, and simulation-based validation is in progress.

8. CONCLUSION

This study establishes a robust CAD–FEA based framework for enhancing the performance and reliability of industrial air-cooling units. By identifying and correcting structural and airflow deficiencies through numerical analysis, significant improvements in vibration behavior, airflow uniformity, and mechanical stability can be achieved. The proposed approach provides a practical and industry-ready solution for upgrading conventional ACUs used in Indian refrigeration systems

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