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A State-of-the-Art View on Design Enhancement of Air-Cooling Unit by Inspecting Its Performance under Various Design Aspects

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ABSTRACT

Air cooling is essential in cold storage industries to maintain a consistent temperature lower than the atmospheric level, ensuring the proper preservation of perishable goods. Effective air cooling is critical for the storage of materials such as vegetables, fruit pulps, grains, and fruits. The optimal storage temperature varies depending on factors like the cooled air temperature, air flow rate, storage capacity, and the cooling medium used. Air Cooling Units (ACUs) play a vital role in achieving and maintaining these conditions. However, it is crucial to design and evaluate the performance of ACUs before installation to ensure their effectiveness. This paper presents a comprehensive review of the performance of ACUs and discusses design enhancements based on identified shortcomings. The design process involves both structural and thermal analysis. Initially, relevant literature on ACUs is reviewed to identify existing research gaps. Based on this review, a methodology is proposed to evaluate the performance of ACUs using Finite Element Method (FEM) under both structural and thermal loads.

***Keywords:** Air Cooling Performance, Air Cooling Units, Finite Element Method, Structural Analysis, Thermal Analysis.*

1. INTRODUCTION

Air-Cooling Units (ACUs) are devices utilized to chill or freeze items stored in enclosed spaces such as cold rooms or cold storage facilities. Industrial ACUs are likewise utilized in large buildings to cool the air through AHU systems. ACU comprises several parts such as a fan, motor, sheet metal framework, support beams, defrosting elements, and the primary part, the refrigeration coil circuit, which includes fins, tubes, and headers for connections. The operation of an ACU is very similar to that of the evaporator section in a home refrigerator [1]. The Coil holds cooled refrigerant that moves into a circuit, while the fan moves air from a sealed space to achieve the desired temperature. Figure 1(a) illustrates the installation of ACU in the cold room. The structure is mounted on wall through structural member.

The fundamental components of ACUs include the coil section, fan section, support framework, drainage system, and defrosting mechanism. Each element of the essential ACU design has a crucial function; for example, the fan connected to the motor circulates air, the coil section is responsible for absorbing heat from the cold room, and the defrosting mechanism removes frost from the fins to enhance performance. The support structure assists in securely holding each component in place, etc. Certain high-capacity ACUs are necessary depending on the cooling needs of various industries, prompting the development of design modifications such as the multiple fan ACU illustrated in Figure 1(b).

The design and production of ACU involve several intricate processes. At first, customer needs were gathered along with key factors such as total heat load, volume needing cooling, and installation space. This data informed decisions regarding fan sizes and quantities, motor specifications, and additional accessories. The support framework was created to hold up the complete assembly [3]. All production is done using traditional manufacturing techniques. The production commenced with sheet metal components such as End plates, Top Pan, Drain Tray, etc. Following that, the manufacturing process involved utilizing a metal cutting machine, bending the sheet metal, welding them, and finally assembling the unit and also there is optimum process selection for every part of ACU [1, 4].

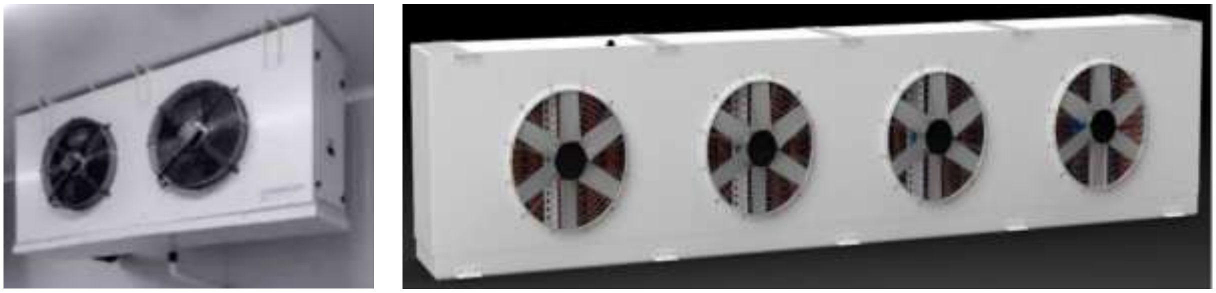

Figure 1. (a) Double Fan Air Cooler Unit, (b) Multi Fan Air Cooling Unit

Upon finishing the assembly, initial testing is conducted to verify the performance of the air cooling unit, ensuring that the customer receives a unit that meets their specifications. The initial test is conducted to verify that the air cooling unit delivers the necessary airflow that encompasses the entire room specified by the customer. The second test is conducted for both the air side pressure drop and the refrigerant side pressure drop, as a reduction in air pressure affects the airflow. A majority of the units experience this issue due to frosting. A pressure drop on the refrigerant side assists in recognizing performance issues [11]. The third test has been completed for defrosting techniques such as water defrosting and heater defrosting. Certain units experience issues with this; for water defrosting units, water isn't evenly distributed across the fins, while heater defrosting heaters struggle to function effectively in units with long fin lengths [12]. Final testing is conducted for structural stability, as the air-cooling unit operates with simultaneous heating and cooling, which influences the structure. Additionally, with a longer fin length, the unit's weight increases due to the higher number of fans, motors, and additional moving parts [10].

In addition to the mentioned tests, Finite Element Analysis (FEA) was employed to examine the static and dynamic behavior of the ACUs. The FEA assessment comprises,

• Static analysis of structures. This kind of FEA examines a model that is scaled according to proportions. The test argues that any structure functioning well on a small scale will manage the same interactions with the full-scale structure and yield identical results [5, 6].

• Analysis of thermal engineering. This test examines changes in temperature and their impact on the design structure. Since the main purpose of ACU is to maintain the temperature at desired level.

• Analysis of modes. Every object oscillates at a frequency, making it essential to employ modal analysis to assess how external vibrations impact the product's integrity. This type of finite element analysis enables users to account for vibrations during the design phase, resulting in a robust final product [9].

• Fluid Dynamics Computation. This exam employs numerical analysis and data structures to examine and resolve issues related to fluid flows. Computers are utilized to carry out the calculations necessary to mimic the free-stream flow of the fluid and the interaction between the fluid (liquids and gases) and surfaces defined by boundary conditions.

2. LITERATURE REVIEW

Shuhui Ding et al, discovered a temporary support system that can adjust to the irregular roof of the roadway. They examined and improved the system and its tools, successfully addressing the challenge of effective temporary support amid the roadway heading face's complicated geological conditions while ensuring smooth cooperation among multiple pieces of on-site equipment. Initially, the mechanical properties of the wall rock support system in the coal mine roadway were examined, establishing a data foundation for the temporary support plan. Subsequently, a new self-propelling temporary support system and its apparatus were suggested, and the static, modal, and fatigue finite element analysis of its design was performed to validate its safety [1].

Yaqin Wang researched the micro reducer components utilizing different materials. As material science progresses, new materials keep appearing. Selecting new engineering plastics for internal and planetary gears can enhance the mechanical efficiency of the micro reducer while minimizing noise and vibration. In the overall structural design, enhancing mechanical efficiency can be achieved by choosing the suitable distribution of transmission ratios and opting for a higher transmission ratio in the high-speed stage. In choosing and organizing the quantity of planetary gears, adopt a suitable approach to enhance the reducer's bearing capacity while taking into account the mechanical enhancement [2].

S. S. Wane Et al. examined the current structure of the college auditorium, which presented issues of poor ventilation and discomfort in many areas during events. A significant portion of the structure is exposed to sunlight, causing the roof to warm up during the day. The aim of air cooling is to create a consistent thermal setting that ensures comfort for most occupants regardless of the various climatic conditions the building faces [3].

Hussein Younus Razzaq Et al. discovered that the rising demand for machine tool products and their growing technological intricacy pose challenges for enhancing and innovating methods in product development processes. The research study investigated the use of an integrated tool to establish an effective prototype during the early phases of the product development process. The Mechatronic design process offers an interactive modeling experience, architectural challenges, and crucial prototyping, while Mechatronics is significantly affected by smart and intelligent devices for real-time observation [4].

Chunlei Yu et al. discovered that their paper presents an analysis of mechanical behavior and structural enhancement of the wrecker's bracket arm, utilizing finite element methods and validation through experimental testing. In comparison to the stress test experiment, the FEM correction put forward in this paper has been confirmed, and its computational precision satisfies the needs for engineering applications. The mechanical behavior under six typical operating conditions has been analyzed, and the critical conditions for each component have been identified. Building on the stress distribution under hazardous conditions, enhancements to the structure have been implemented, and the mechanical performance of these improved structures has been examined as well. Numerical simulation findings indicate that the peak equivalent stresses of the primary components of the bracket arm have all decreased to levels below the permissible stress [5].

Ersin Toptas discovered that a component utilized as a bicycle girdle on the neck was created using artificial intelligence-based, generative design techniques. Using this model that developed in this manner, it was possible to design a model that offers the required mechanical strength and lightweight properties under the specified conditions. His design employs machine learning to replicate nature's method of design. Designers or engineers specify design parameters, and the software swiftly explores all potential solution combinations by generating hundreds or even thousands of design alternatives. Thus, a creative approach framework for the designer to address these intricate engineering challenges arises. The evolution of contemporary engineering systems has led to growing complexity and uncertainty over the years. At times, it can consume a considerable amount of time to address these uncertainties using the traditional method [6].

Botao Zhang et al. explored the development of a virtual toolset that automatically produces CAD-based support structures, identifies crucial geometric features harmful to the AM process, suggests the ideal number of setups for removing support structures, and optimizes the build orientation for specific part geometries. All these functionalities are incorporated into the Siemens NX CAD environment through GUIs that enable the user to enter personalized parameters. The tool produces visual results to give the user feedback on every aspect of feature development discussed in their paper [7].

Suresh Kumar Kandreegula et al discovered a strong correlation between the outcomes of FEA analysis and experimental results, supporting the method used in FEA simulations, which could substantially decrease both design time and prototype testing. A novel method for designing and developing propeller shaft mounting systems, utilizing FEA simulation analysis, is established, which can significantly reduce development costs and time. The procedure can likewise be standardized for the creation of propeller shaft mounting systems on all existing vehicle platforms, providing long-term advantages for the organization [8].

Bikrant Rauniyar et al reported that this paper presents the working principles and fundamental characteristics of air conditioning systems. As living standards have risen, air conditioning has become commonly used. The rising demand for comfortable air-conditioning has created a necessity for more practical, technical, and sales personnel who possess training in the fundamental principles and applications of contemporary air-conditioning [9].

M. M. Muhsen et al. conducted a study that experimented with two air-cooled compact heat exchangers to enhance indoor air quality during the summer in Iraq. The design of the rig is arranged so that air passes through a two-stage direct/indirect cooling system to reduce the elevated air temperature. The water in the unit's basin was subsequently transferred to the second stage as a working fluid [10].

3. CHALLENGES TO DEVELOPMENT

Star Coolers and Condensers Private Limited. (Founded in 2000) is the subsidiary of Coolers and Condensers, located in England for the past 50 years. These firms produce the heat exchangers utilized in industrial refrigeration systems. SCCPL utilizes the design from their parent companies that was created over 20 years ago, with only minor updates to the design since then. Some time ago, SCCPL intended to enhance their design according to Indian

Standards appropriate for Indian weather and operational conditions. They attempted to adjust certain parameters but were unsuccessful in enhancing the design according to Indian standards. Consequently, to adapt new technologies in heat exchangers and enhance the performance of their equipment, design optimization and improvements are necessary.

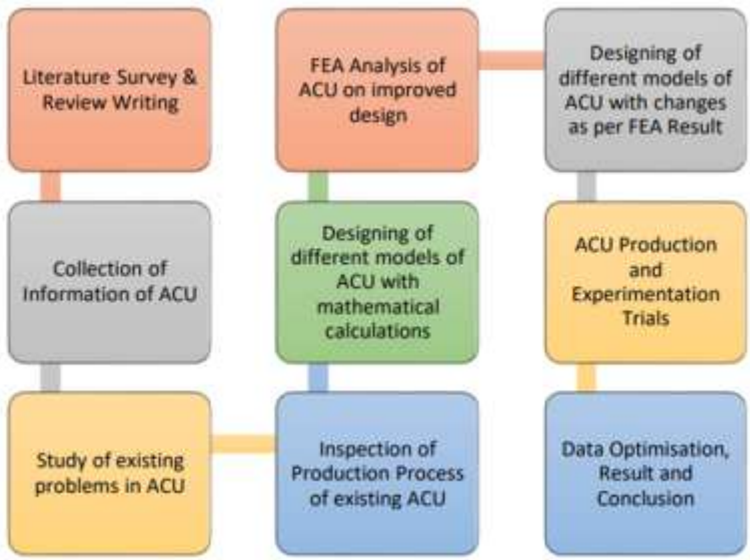

Figure 2 Proposed Methodology

3.1 Proposed Methodology

The methodology employed in this research is a Computational design and drawing, and Finite element-based strategy for production of models. The various process flow is shown in Figure 2.

a) Literature Survey & Review Writing

First take a survey of the market for companies which produces the Air-Cooling Units. Once the company found then collection of information about Air cooling Units and their production process as well as the productions problems and working problems.

b) Collection of Information of ACU

After collecting required information and literature the important part to collect information regarding the manufacturing of ACU and their different types. Also to understand the working principal and selection criteria, duty offered by the ACU.

c) Study of existing problems in ACU

By checking designing process as well as production process of ACU for identification of different problems such as dimensional error, fitment problems, not proper alignment and output given by ACU. Also referring competitors design for better performance.

d) Inspection of Production Process of ACU

As per requirement there is need change production design which allows the production process to improve fluency of it. Also, some area where change in design helps the production process such as change in fan fixing position, etc.

e) Designing of Different models of ACU with mathematical Calculation

As per requirement from the customer and design offered by the competitor to overcome all problems in the design of ACU. Making the trial models using different types of mathematical calculation which are implemented for modification of existing design.

f) FEA Analysis of ACU on improved design

After designing different models of Air-cooling unit first trials taken are on the Finite element analysis for considering the optimum sturdy design, and the design useful for production. Also, the analysis of duty offered by the air-cooling unit to overcome the heat load offer by the cold storage and product in the cold storage.

g) Designing of different models of ACU with changes as per FEA Result

Again, FEA analysis will be carried out using new design and sheet metal section criteria. FEA analysis in static mode gives the good idea on the design of it and performance of the unit. Changing design according to the Finite element results gives the better idea for improvement designing ACU and working of it.

h) ACU Production and Experimental Trials

After all trial on Design using Finite element analysis the production trials will be taken for actual trial to find out the performance and optimum design selection. Actual production also helps to improve the vision of errors and problems in production process.

i) Data Collection, Optimization, Result and Conclusion

After all the FEA trials and Experimentation collected data is compared with each other and optimum design of the ACU and optimum production process will be taken out.

4. CONCLUSIONS

In this paper the experimental and Finite Element approach helps to optimize the design and structure of air-cooling unit for social and economic purposes. The expected outcomes from this paper are as follows.

- Analyzing the underlying causes of issues aids in determining how to address the problems present in ACU. It could be beneficial to pinpoint a specific mathematical method for discovering a more effective solution that enhances the design. Recognizing issues in parts design aids in reducing waste and utilizing sheets of varying thickness for cost-effective production of Air-Cooling Units.
- Identification of remedies for issues in current design of ACU structure which aids in enhancing the design of machine components. In this instance, enhanced design and structural integrity contribute to extending the lifespan of the Air-Cooling Unit.
- Finishing the production trial with an enhanced design allows for testing the unit at the real work site to improve performance and other factors. Conducting the production trial and experimental research aids in identifying the comparison between the old design and the improved design.
- The utilization of FEA tools enables us to discover design and performance solutions without incurring unnecessary time and costs in creating prototypes of Air-Cooling Units. Additionally, it enhances the comprehension of errors and aids in validating the enhanced design.
- Utilizing the Optimization method verifies the effective design through numerical solutions and conserves time in choosing the best approach for design.

5. REFERENCES

[1] Shuhui Ding, Jindong Bai, Jingliang Han, Haixia Wang and Fai Ma, “Mechanical Characteristics Analysis and Structural Optimization of Key Component of Self-Moving Temporary Support,” Appl. Sci. 2022, 12, 10745. https://doi.org/10.3390/app122110745

[2] Yaqin Wang, “Design and Mechanical Efficiency Improvement of Micro Reducer”, Journal of Physics: Conference Series, IOP Publishing, 2338 (2022) 012082, doi:10.1088/17426596/2338/1/012082

[3] S. S. Wane and M. B. Nagdeve, “Design of Air-Cooling System for College Auditorium”, Journal of Environmental Research and Development (2012) Vol. 6 No. 3, Jan-March 2012 page no. 562 – 568.

[4] Hussein Younus Razzaq, Hussein Mohammed Hasan, Kadhim Raheem Abbas, “Machine Design Modern Techniques and Innovative Technologies”, Journal of Physics: Conference Series, IOP Publishing, 1897 (2021) 012072, doi:10.1088/1742-6596/1897/1/012072

[5] Chunlei Yua, Yingchao Baoa and Chao Chen, “Mechanical behavior analysis and structural improvement for the bracket arm of wrecker”, Journal of Computational Methods in Sciences and Engineering -1 (2021) 1–14, DOI 10.3233/JCM214906

[6] Ersin Toptas, “Innovative approach to the design of mechanical parts”, Journal of Mechatronics and Artificial Intelligence in Engineering. June 2020, Volume 1, Issue 1, page no. 14 – 20, Doi: https://doi.org/10.21595/jmai.2020.21473

[7] Botao Zhang, Archak Goel, Omkar Ghalsasi, Sam Anand, “CAD-based design and pre-processing tools for additive manufacturing”, Journal of Manufacturing Systems 52 (2019) 227–241.

[8] Suresh Kumar Kandreegula, Sayak Mukherjee, Rahul Jain, Shivdayal Prasad, and Kamal Rohilla, “FEM based Approach for Design and Development of Exhaust System Flex Connector and Experimentally Validated”, SAE Technical Paper, 2017-01-1079, 2017, doi:10.4271/2017-01-1079.

[9] Bikrant Rauniyar, Harsimran Singh Sodhi, “Research on the Air Conditioning System” , Suraj Punj Journal For Multidisciplinary Research, ISSN NO: 2394-2886, Volume 8, Issue 12, 2018, Page No:179 – 182.

[10] M. M. Muhsen, A. A. Abdulrasool and B. R. Sadiq, “Experimental study on performance improvement of air cooler incorporating two-stages,” 4th International Conference on Engineering Sciences (ICES 2020), IOP Conf. Ser.: Mater. Sci. Eng. 1067 012112, doi:10.1088/1757-899X/1067

[11] Hua Yang , Na Pei , Man Fan , Liansheng Liu , Dongji Wang, "Experimental study on an air-cooled air conditioning unit with spray evaporative cooling system" , International Journal of Refrigeration (2021), https://doi.org/10.1016/j.ijrefrig.2021.06.011.