APPLICATION OF TECHNO-ECONOMICS IN THE DESIGN OF COOLING MACHINE DUCT FOR LABOR SCALE MECHANICAL ENGINEERING MUHAMMADIYAH UNIVERSITY OF WEST SUMATERA

[1]Alfito Suherman,[*2]Riza Muharni,[3]Muchlisinalahuddin
[4]Jana Hafiza,[5]Dycthia Septi Kesuma

[1,2,3,4,5]*Faculty of Engineering, Universitas Muhammadiyah Sumatera Barat, Indonesia*

Author's email:
[1]*tahasak@upr.ac.id*; [2]*rizamuharni12@gmail.com*; [3]*muchlisinalahuddin.umsumbar@gmail.com*
[4]*janahafizaumsb@gmail.com*; [5]*dycthia@gmail.com*

**Corresponding author:rizamuharni12@gmail.com*

Abstract. *The cooling machine duct is an air duct used to deliver cold air to the room. This cooling machine channel is used to observe changes in temperature, humidity, enthalpy and air flow rate against heat transfer. This study focuses on the design and manufacture of laboratory-scale cooling machine channels by applying techno-economics. The results show that this cooling machine channel test tool is suitable for use in mechanical engineering laboratory experiments with lower operational costs and meets laboratory needs.*

Keywords: *Cooling machine; Duct; Laboratory; Techno-Economy*

1. INTRODUCTION

The availability of an efficient and suitable cooling system for laboratory scale is a crucial aspect in supporting the practical-based mechanical engineering learning process (Asadi, Mohammadagha, and Naeini 2025) Cooling systems play a crucial role in the simulation and visualization of fundamental thermodynamic phenomena, thus enhancing students' conceptual understanding and technical skills. However, the reality in the field shows that the cooling systems used in laboratories are generally adaptations of industrial- or household-scale systems, which are functionally and structurally inadequate for the educational needs and limited laboratory space (Taimoor et al. 2022)

The main problem identified was the absence of a specific cooling system duct design for laboratory scale, which integrates thermal effectiveness with cost efficiency (Taimoor et al. 2022) Furthermore, limited budgets for educational institutions to procure adequate engineering demonstration equipment pose a significant obstacle to providing optimal experimental facilities. This situation has the potential to hinder the application of learning and reduce the quality of students' understanding of the working principles of cooling systems (Kumar et al. 2020)

The application of a techno-economic approach is a relevant strategy in addressing these challenges. By integrating technical aspects (such as airflow design, heat transfer effectiveness, and material selection) with economic considerations (such as production cost efficiency and ease of assembly), it is hoped that a design solution will be created that is not only reliable in performance but also financially feasible for application in educational environments. This study aims to design a cooling machine duct system based on a techno-economic approach intended for educational-scale mechanical engineering laboratories (Samir et Al, 2020) The main focus of the research includes optimizing the duct's mechanical design, selecting economical and locally available components, and evaluating the system's thermal performance against engineering learning needs. The results are expected to serve as a reference in the development of efficient, educational, and cost-effective mechanical engineering lab tools (Saini et al., 2021)

2. LITERATURE REVIEW

2.1 Basic Concepts of Refrigeration Systems and Ducting

a. Working Principle of Refrigeration Machines

Refrigeration machines operate based on the principle of heat transfer, absorbing heat from one location (the space to be cooled) and rejecting it to the environment. This process typically involves a thermodynamic cycle, such as the vapor compression cycle, which consists of four main components: a compressor, a condenser, an expansion valve, and an evaporator. The working fluid (refrigerant) undergoes changes in pressure and temperature to absorb and release heat (Muharni et al. 2023)

b. Function of Ducts in Refrigeration Systems

Ducts, or air channels, play a crucial role in refrigeration systems, particularly in channeling cool air from the evaporator to the intended space. Furthermore, good duct design will minimize pressure losses and leaks, and increase heat transfer efficiency. In the context of a mechanical engineering laboratory, ducts should also allow for easy observation of flow parameters for educational and research purposes (Najini et al. 2020)

2.2 Duct Design Study

a. Duct Design Methods

Duct design can be performed through theoretical approaches and numerical simulations, considering the flow type (laminar/turbulent), duct configuration (rectangular or circular), and space requirements. Popular methods such as the equal friction method, velocity reduction method, and static regain method are used to determine optimal duct dimensions and minimize pressure losses (Saini et al., 2021)

Technical Parameters in Duct DesignSome important parameters in duct design include:

1. Air velocity: Affects air distribution efficiency and noise levels.
2. Pressure (static and dynamic pressure): Related to fan performance and flow resistance.
3. Duct cross-sectional area: Determines flow velocity and pressure.
4. Pressure losses: Pressure loss due to friction with duct walls and changes in flow direction.
5. System efficiency: A combination of all technical factors that impact energy consumption and thermal comfort (R & Hudha 2019)

2.3. Techno-Economic Approach

a. Definition of Techno-Economic Analysis

Techno-economic analysis is an approach that combines technical and economic aspects in the design process and engineering decision-making. The goal is to achieve a design that is not only optimal in terms of performance but also cost-effective. In the context of cooling systems, this means considering thermal performance and production, installation, and operational costs (Toupin et al., 2016)

b. Examples of Techno-Economic Applications in Engineering Systems Design

Examples of its application include:

The selection of materials with competitive prices is based on a techno-economic approach. Suggestions for further development that can be carried out in subsequent research are also presented, both in terms of increasing system efficiency and optimizing production costs (Ercan M. dede, Chi Zhang, Qianyying wu, Kenneth E, Goodson, Roman Giglio 2022)

3. RESEARCH METHODS

This research is an engineering research with a design and experimental approach, which aims to design and test a refrigeration duct system based on a techno-economic approach at a laboratory scale. The research activities were carried out from March to July 2025, and the stages passed in this study are shown in the flow chart in Figure 1.

Figure 1. Flow Chart

1. Start

Research begins with determining the topic and identifying the urgency of the problem to be studied. This stage includes formulating the background, objectives, and scope of the research. This process also involves developing a general work plan, including identifying resources and implementation timelines, which serve as the foundation for implementing subsequent stages.

2. Literature Study

This stage aims to build a strong theoretical foundation through a literature review. The literature reviewed includes technical concepts regarding cooling systems, duct design, heat transfer principles, and techno-economic approaches to engineering equipment design. Furthermore, relevant previous research is reviewed to identify research gaps and support the validity of the design to be developed.

3. Problem Identification

After gaining a theoretical understanding, real-world problems in a mechanical engineering laboratory environment are identified. These problems include the limited availability of suitable cooling equipment for laboratory scale, both from a technical and economic perspective. At this stage, the problem statement and research limitations are formulated, which will serve as the basis for the design and testing of the system to be developed.

4. Design

The design phase begins with the creation of a model of the refrigeration duct system suitable for laboratory scale. The design is performed using CAD (Computer-Aided Design) software such as SolidWorks, taking into account airflow, thermal efficiency, and economical component selection. A Cost Budget Plan (RAB) is also prepared as part of the economic evaluation of the design process.

5. Analysis

The analysis in this study focuses on techno-economic aspects. An evaluation was conducted on the budget (RAB) to measure the total cost of manufacturing the equipment and assess its efficiency compared to the resulting benefits. This analysis aims to assess the feasibility of the designed system for implementation and replication on a laboratory scale within budget constraints.

6. Results and Discussion

The results obtained from the design and testing process are then presented systematically and critically discussed. This section presents the design results, tool performance tests, and interpretation of technical and economic data. The discussion is conducted by linking the research findings to previously reviewed theories and comparing them with previous research to assess the innovation and contribution of this research.

7. Conclusion

Finally, the conclusion stage summarizes the entire research process and results. The conclusion contains answers to the research problem formulation and objectives, and evaluates the success of the refrigeration duct system design based on a techno-economic approach. Furthermore, suggestions for further development that can be implemented in future research are presented, both in terms of increasing system efficiency and optimizing production costs.

4. RESULTS AND DISCUSSION

This study applies a techno-economic approach to the design of a cooling machine duct, considering component selection based on functional specifications and cost efficiency. The Cost Budget Plan (RAB) was prepared systematically.

This approach aims to produce a cooling system design that optimizes thermal performance, ease of assembly, and cost efficiency. Thus, this design not only meets the needs of practical learning but also represents the basic principles of integrated techno-economic-based thermal systems engineering.

Table 1. RAB

No	TOOL NAME	FUNCTION	PRICE
1	Refrigerator compressor	Increasing the pressure of a fluid or gas by reducing its volume	320.000
2	Evaporator	Absorbs heat from the air in the room, so that the air becomes cool.	50.000
3	Kondensor	Converting high pressure gas from the compressor into liquid, through a process of releasing heat to the surrounding environment.	70.000
4	Fan	Generate and direct air flow for various purposes	60.000
5	Heating element	Converting electrical energy into heat. Heating elements work by passing an electric current through a material with high resistance, thereby producing heat.	25.000
6	Copper pipe	Piping systems, both for clean water, hot water, and cooling systems such as air conditioning	46.000
7	Copper capillary tube	Reduces the pressure of refrigerant in a refrigeration system, regulates the flow rate of refrigerant, and is also used in small volume measurement and other laboratory applications.	12.000
8	Alumunium foil	Keeps cold and hot temperatures from escaping	25.000
9	Silicon	Sealing materials, adhesives, coatings, and in the manufacture of electronic components	23.000
10	Cam stater	Electric current converter to hot or cold	55.000
11	Cabel	Conducting electricity or signals, and connecting components in an electrical system or network	18.000
12	Zinc plate	Building material for barriers on tools	25.000
13	Bolt	As a binding tool to unite two or more components	40.000
14	Dimmer switch	Set the fan speed	30.000

The cooling duct system design shon in Figure 2 is the final result of a techno-economic engineering process. This design depicts a horizontal duct structure supported by a metal frame and equipped with key components such as a compressor, condenser, evaporator, and fan, integrated at the center and ends of the system. In this design, air is circulated through a closed duct using a fan (fn) installed at the end of the system. The evaporator is placed at the air inlet to absorb heat, so that the air exiting the opposite side has experienced a temperature drop. The condenser and compressor components are placed on the underside of the duct and connected to a copper piping system, as described in the Bill of Quantities (RAB). The selection of materials and components such as aluminum foil, copper capillary tubes, and silicone insulation is intended to maintain thermal efficiency while reducing energy leakage during the cooling process.

The zinc plate frame structure and bolted fastening system reflect the use of affordable yet robust materials to support laboratory-scale cooling systems. Ergonomically and educationally, this design allows for direct observation of cool air flow, temperature regulation, and heat transfer, making it ideal for mechanical engineering practicals.

The total system cost of Rp 799,000, as analyzed in the previous section, represents an economically efficient design while still meeting the required technical functions. The design not only considers efficient airflow and heat transfer but also optimizes modularity and affordability, allowing for easy replication by other educational institutions.

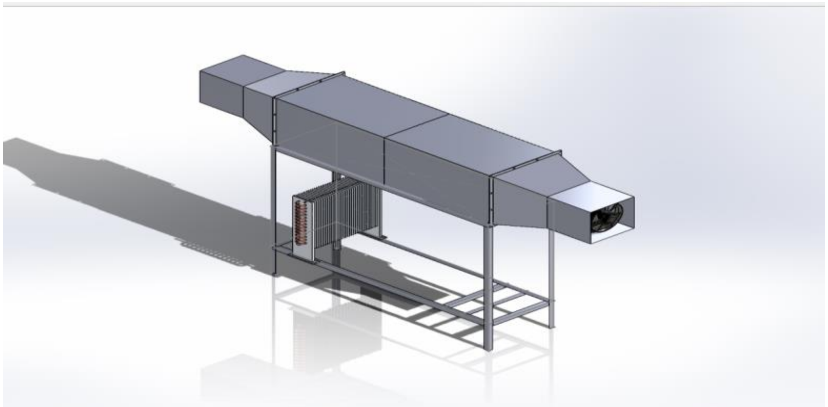

Figure 2. Scale

Thus, the design of this cooling duct system has successfully translated the techno-economic approach into a real, measurable, and applicable physical form in a mechanical engineering laboratory environment.

Figure 3. Results

The image shown is a visual documentation of an experimental unit of a cooling ducting system designed for educational and research purposes at the Mechanical Engineering Laboratory of the University of Muhammadiyah West Sumatra. This tool is designed based on a thermal systems engineering approach, taking into account thermodynamic efficiency, ease of component integration, and cost analysis (techno-economic assessment). This design represents the application of mechanical engineering principles in the development of engineering-based teaching aids, as well as a concrete form of integration between technical efficiency and cost effectiveness in the design of an experimental cooling system.

CONCLUSION

Based on the design results, cost analysis, and applied techno-economic approach, it can be concluded that the development of a cooling machine duct system for a mechanical engineering laboratory scale has been successfully realized effectively and efficiently. This system was designed by considering the educational needs in understanding the basic principles of thermodynamics and air flow, as well as the budget constraints generally faced by educational institutions.

The Budget Plan (RAB) analysis revealed that the total system construction cost reached Rp 799,000, with the compressor, evaporator, and condenser accounting for the largest cost. However, this cost is still very economical compared to commercial cooling systems, without compromising the device's primary function as a learning tool. The selection of locally sourced materials and components contributes to cost efficiency and the availability of spare parts for long-term maintenance.

From a design perspective, the duct system visually demonstrates airflow arranged in a linear configuration through a closed channel, supported by a stable and easily accessible frame and component mounts. This structure provides clarity of the function of each component, making it highly suitable for use in practical learning in mechanical engineering laboratories.

Overall, this research demonstrates that a techno-economic approach can be implemented effectively in the design process of a simple cooling system, resulting in a device that is technically, economically, and educationally feasible. The resulting design not only provides cost efficiency but also opens up opportunities for replication and further development for research and teaching purposes.

REFERENCES

Asadi, S, M Mohammadagha, and H K Naeini. 2025. “Comprehensive Review of Analytical and Numerical Approaches in Earth-to-Air Heat Exchangers and Exergoeconomic Evaluations.” ArXiv Preprint ArXiv:2502.08553

Ercan M. dede, Chi Zhang, Qianyying wu, Kenneth E, Goodson, Roman Giglio, Mehdi Asheghi. 2022. “Techno-Economic Feasility Analysis of an Extreme Heat Flux Micro-Cooler.” IScience.

Hanifa R., Nur Hudha, Wisnu K. 2019. “Analisa Kebutuhan Beban Pendingin Untuk Aula Kampus III UM Beban Pendingin Untuk Aula Kampus III UM Sumatera Barat” 1 (2): 55–60.

Kumar, Dileep, Sanjay Kumar, Bilawal Ahmed Bhayo, Khanji Harijan, and Muhammad Aslam Uqali. 2020. “Economic and Environmental Impacts of Thermal Insulation Used in Different Duct Sizes.” Journal of Thermal Engineering 6 (1): 141–56. https://doi.org/10.18186/THERMAL.672085.

Muharni, Riza, Agus Afrianda, Wenny Martiana, and Dytchia Septi Kesuma. 2023. “Assalamualaikum Buk Proposal Alfito Suherman Sudah Acc Samo Buk Jana Buk Tinggal Dari Ibuk Lai Buk.” JURNAL Teknik Mesin 16 (1): 30–36. http://ejournal2.pnp.ac.id/index.php/jtm.

Najini, Hiba, Mutasim Nour, Sulaiman Al-Zuhair, and Fadi Ghaith. 2020. “Techno-Economic Analysis of Green Building Codes in United Arab Emirates Based on a Case Study Office Building.” Sustainability (Switzerland) 12 (21): 1–22. https://doi.org/10.3390/su12218773.

Saini, Abhishek, Sarah J. Watzman, and Je Hyeong Bahk. 2021. “Cost-Performance Trade-off in Thermoelectric Air Conditioning System with Graded and Constant Material Properties.” Energy and Buildings 240:1–27. https://doi.org/10.1016/j.enbuild.2021.110931.

Taimoor, Aqeel Ahmad, Usman Saeed, Sami Ullah Rather, Saad Al-Shahrani, Hisham S. Bamufleh, Hesham Alhumade, Aliyu Adebayo Sulaimon, Walid M. Alalayah, and Azmi Mohd Shariff. 2022. “Economic and Technical Analysis of a Hybrid Dry Cooling Cycle to Replace Conventional Wet Cooling Towers for High Process Cooling Loads.” Energies 15 (21). https://doi.org/10.3390/en15217986

Tekno Eko, Samir et Al, 2020.Pdf.” n.d.

Toupin, Mathieu, Kourosh Malek, and Asmae Mokrini. 2016. “Techno-Economics of a New High Throughput Process for Proton Exchange Membranes Manufacturing.” EVS 2016 - 29th International Electric Vehicle Symposium 8:431–42.