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Design of Practical Tools for Achievement of $\frac{3}{4}$ PK Split AC Cooling System Laboratory Scale Dian Nusantara University

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Abstract: This design aims to design and build a laboratory-scale refrigeration test tool that can be used to test the performance of a cooling system under various operational conditions. The design process for this test equipment involves several stages, from requirements analysis and mechanical and electronic design to fabrication and testing. Some of the features implemented in this equipment include precise temperature control, a digital monitoring system, and the ability to test various types of refrigeration systems. The expected outcome of this test equipment is the ability to provide accurate data on refrigeration system performance, which can then be used to improve energy efficiency and cooling system performance in industrial applications.

Keyword: Design, Refrigeration Test Equipment, Laboratory Scale, Cooling System, Energy Efficiency.

INTRODUCTION

In the learning process, the presence of laboratory equipment is an important tool to help students understand and deepen the material being studied. In the Mechanical Engineering curriculum, the material taught is quite broad and diverse, one of which is refrigeration and heat transfer, which are generally taught at the tertiary level. Therefore, developing learning modules equipped with appropriate laboratory equipment is a crucial need to support effective learning. The teaching aids used in learning must be designed in harmony with the teaching material and able to represent the concepts being studied. (Mulyati, 2015). The laboratory, as a place for conducting experiments and analysis, plays a crucial role in supporting these activities. The development of laboratory-scale test equipment allows for more focused and systematic observation and learning processes. (Augustinus Purna Irawan, 2018).

This research developed a laboratory-scale performance test tool for a ¾ HP AC-based refrigeration system. This system is designed to simulate the refrigeration process in a simple and easy-to-understand manner, making it suitable for use as a learning tool. The design involved planning and calculations that took into account theoretical concepts and safety aspects such as material selection and structural strength.(Stenly Tangkuman, 2019)This lab tool uses R32 refrigerant and is designed to be portable for greater flexibility. The development of this tool is expected to support observations on the performance of the cooling fluid, energy changes in the refrigeration cycle, and various phenomena that occur in the system.

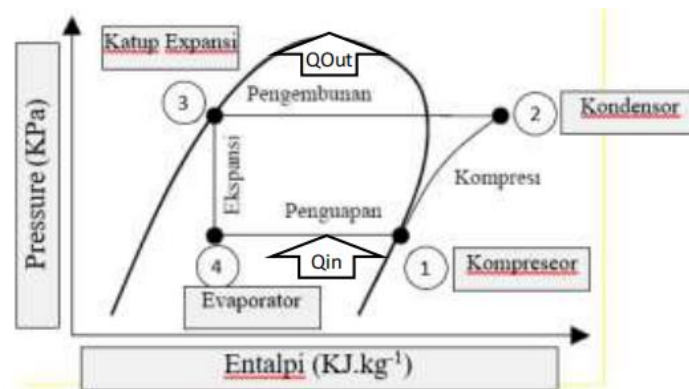


Figure 1.Refrigeration cycle and heat transfer scheme
Source : Design Document

The split type Air Conditioner (AC) system consists of four main components, namely the compressor, condenser, expansion valve, and evaporator which work in one refrigeration cycle.(Wang, 2001)The compressor functions to increase the pressure and temperature of the refrigerant, the condenser releases heat until the refrigerant changes phase to liquid, the expansion valve reduces the pressure and temperature drastically, and the evaporator absorbs heat from the environment.(Shi et al., 2025).

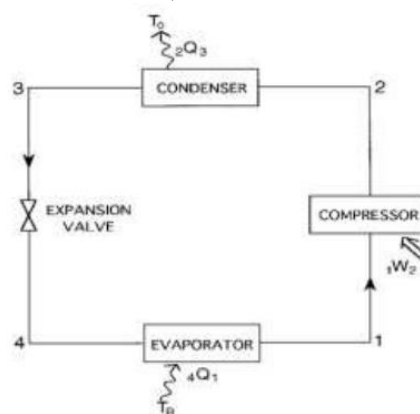


Figure 2.Single Stage Refrigeration Machine Workflow
Source : ASHRAE Fundamentals Hanbook, 2001

The refrigeration cycle that occurs is a vapor compression cycle which consists of the processes of compression, condensation, expansion and evaporation.(Awwaluddin, nd)The performance of the cooling system can be analyzed based on the refrigeration capacity and the Coefficient of Performance (COP) value.(Sugarman, 2005). The constant enthalpy deceleration process assumes no heat transfer or change in potential or kinetic energy through

the expansion valve.(Komarudin, 2022; William H. Motz, 1981). Thus the CoP or coefficient of performance is:

$$CoP = \frac{q_e}{q_w} = \frac{h_1 - h_4}{h_2 - h_1}$$

Where : q_e = evaporation work
 q_w = compressor work

Meanwhile, to calculate the efficiency of the cooling system, based on SNI, the following equation can be used:

$$EER = \frac{CoP}{0.2931}$$

In addition, in designing a cooling system, a cooling load analysis is required, which includes external loads (walls, roofs, floors, windows, and air infiltration) as well as internal loads (humans, lighting, and equipment).(GF Hundy, 2008)This load calculation is important to determine the cooling system capacity that suits the room's needs.(Lukitobudi, 2010).

METHOD

This research method was used to design a laboratory-scale performance test tool for a ¼ HP split AC cooling system. The design stages were carried out systematically to ensure the alignment between the theoretical concept, design, and implementation results.

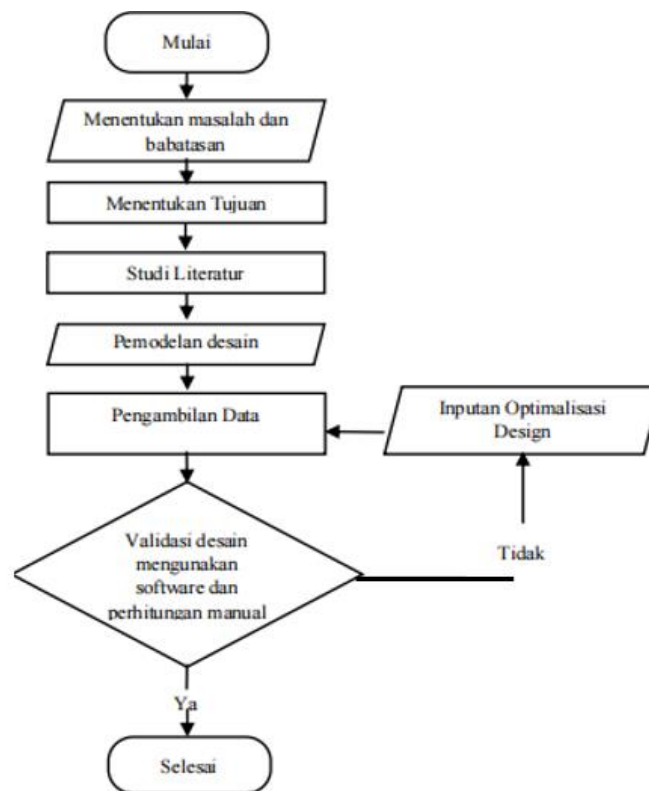


Figure 3. Research Flow Chart

The design process begins with problem identification and defining research boundaries, followed by defining objectives.

Next, a literature review and relevant data collection are conducted to serve as a basis for the design process. The next stage is system design modeling, which is then validated through software simulations and manual calculations.

If the validation results do not meet the expected criteria, design optimization is performed until satisfactory results are achieved. Once the design is declared valid, the design process is complete and ready for implementation.

In writing the design for this final assignment, there are several points that needs to be raised as a problem and evaluation and resolution are required. First of all, this is caused by Dian Nusantara University itself. There are no teaching aids for the Refrigeration System. Second, the design is new, and the equipment has never been previously created or validated.

The design phase begins with modeling the tool design using CAD software, which includes the design of the frame, component layout, and cooling system integration. The frame is designed using SPHC hollow steel, taking into account structural strength, ease of fabrication, and safety factors.(Andar Harianja, 2023). In addition, key components are selected, such as split AC units (indoor and outdoor), temperature and humidity sensors, pressure gauges, and airflow meters.

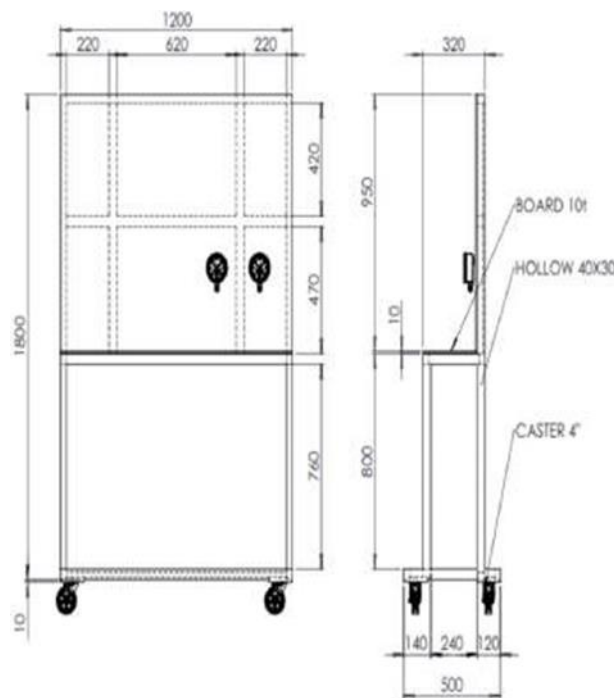


Figure 4. Design and Construction of the Test Equipment Frame
Source: Design Document

Next, a design analysis was performed using two approaches: manual calculations and numerical simulations. Manual calculations were used to determine the cooling system's performance parameters, such as refrigeration capacity, room cooling load, and Coefficient of Performance (COP).(ASHRAE, 2017). Cooling load calculations include external loads (walls, roofs, floors, windows, and infiltration) as well as internal loads (people, lighting, and equipment).(Atlanta, 2005; Huang et al., 2019).

Table 1. Example of Cooling Load Calculation

Item	Net Area, m ²	GLF, W/m ²	U-Factor, W/(m ² . K)	CLTD, K	Cooling Load, kW
Living Room					
West Wall	8,4		0,34	14	0,040
Partition (garage)	17,5		0,40	7	0,049
Roof	44,5		0,28	27	0,336
West door	1,9		1,82	14	0,048

Item	Net Area, m ²	GLF, W/m ²	U-Factor, W/(m ² . K)	CLTD, K	Cooling Load, kW
Living Room					
West glass	3,1	141			0,437
Shaded glass	1,2	63			0,076
Kitchen					
East wall	12,4		0,34	14	0,059
Roof	22,6		0,28	27	0,171
East glass	1,25	141			0,176
Shaded glass	1,0	63			0,063

Source: ASHRAE Fundamental Handbook 2001

Numerical simulations were performed using Finite Element Analysis (FEA) software to analyze the strength of the frame structure. The parameters analyzed included maximum stress, displacement, strain, and factor of safety. The simulation results were used to ensure that the frame design could safely withstand the working loads.

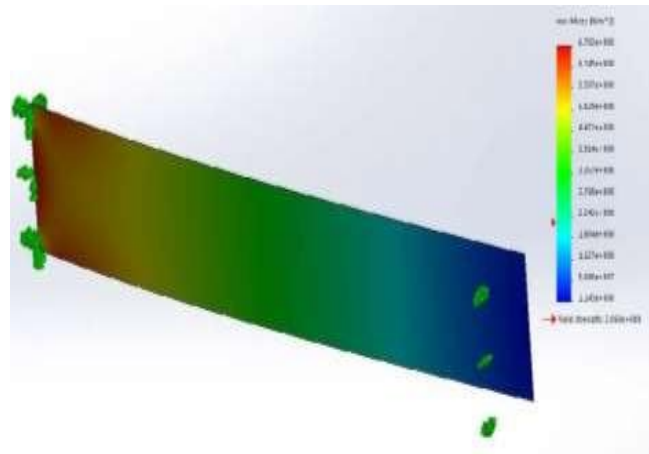


Figure 5. Example of displacement simulation results
Source: Solidworks Product

The validation phase is carried out by comparing the results of manual calculations and simulation results. If the results obtained do not meet the expected design criteria, an optimization process is carried out by adjusting the dimensions, materials, or design configuration until optimal results are obtained. Once the design is declared valid, the next stage is the overall system integration, which includes the installation of the split AC unit, the installation of sensors and measuring instruments, and the development of the control system. In addition, a test chamber is designed with specific dimensions to simulate real-world cooling load conditions.(Febiyani, 2020).

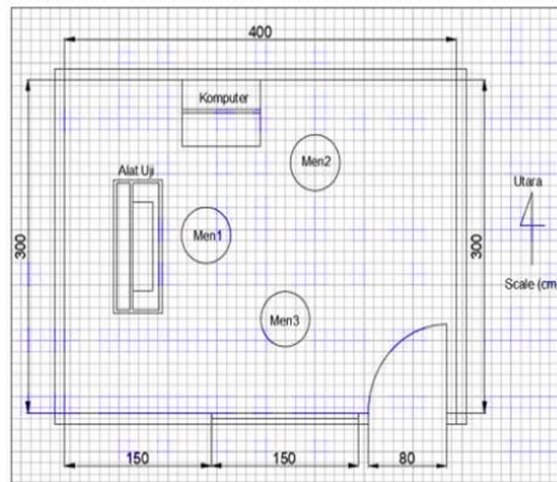


Figure 6. Test Room Layout Design
Source: Design Document

RESULT AND DISCUSSION

The design results in a practical tool for testing the performance of a ¼ HP split AC-based cooling system using R32 refrigerant. The system is designed in a portable form to facilitate mobility and use on a laboratory scale.

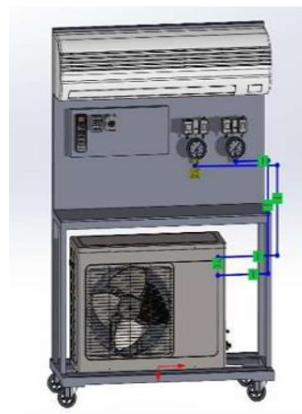


Figure 7. Refrigeration System Test Equipment
Source: Design Document

The device consists of indoor and outdoor AC units, a hollow SPHC steel support frame, and measuring instruments such as a temperature sensor, pressure gauge, and an anemometer. This design allows direct observation of the refrigeration cycle, from compression, condensation, expansion, and evaporation.(Dossat et al., 1961).

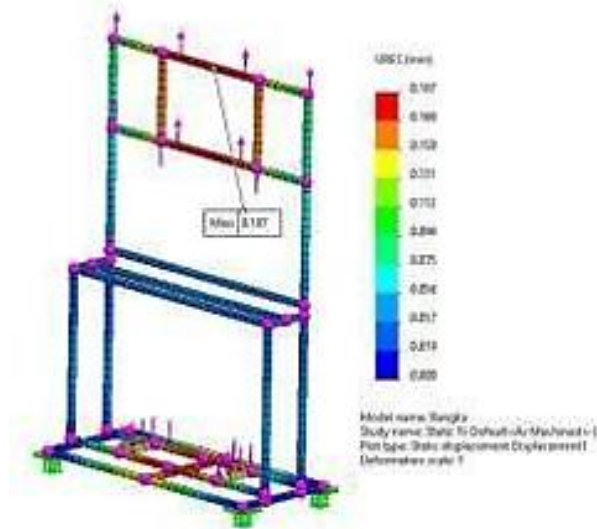


Figure 8. Factor of Safety of the Frame Design Simulation
Source: Design Document

The frame structure analysis was carried out using a simulation method based on Finite Element Analysis (FEA) to determine the distribution of stress, deformation, and safety factors. The simulation results show that the maximum stress is still below the yield strength limit of the SPHC material, thus the structure is considered safe. The deformation value is relatively small and does not affect the overall stability of the system. Furthermore, the obtained Factor of Safety (FSA) is greater than 1, indicating that the frame is capable of withstanding the working load during the operation of the equipment.

Testing was conducted to determine the performance of the cooling system under actual operating conditions. Observed parameters included air temperature, refrigerant pressure, and airflow velocity through the evaporator.

Table 2. Actual Data of Cooling Unit Observations
Source: Design Document

Freon Type	Temp		Pressure		Data Entalpi			
	Comp °C	Evap °C	Comp Bar	Evap Bar	h1 kJ/kg	h2 kJ/kg	h3 kJ/kg	h4 kJ/kg
R32	44	18	27.29	13.95	517	553.4	284.1	284.1
Note: entalpi didapat berdasarkan hasil olah pada software, dengan input data temperatur atau pressure pada evaporator dan compressor								
qw	qe	COP	m	T1	T3	Capacity Ref		
kJ	kJ		Kg/s	K	K	kW		
0,199	1.274	6,40	0,00547	305,15	291,15	1.335		

The cooling load is the amount of heat the cooling system must absorb to maintain the desired room temperature. In cooling system design, calculating this load is a key parameter for determining system capacity and performance. In general, the cooling load consists of two main components: external load and internal load.

Table 3. Actual Cooling Load Observation Data

Beban Pendinginan			
Luar	Infoltrasi	Dalam	Total
0,459 kW	0,177 kW	0,514 kW	1.150 kW

Source: Design Document

The frame structure is the main component in the design of the tool that functions as a support for the entire system load, including the cooling unit, measuring instruments, and other supporting components. The frame is designed to have adequate strength, stiffness, and stability to be able to withstand static and dynamic loads during the operating process. In this study, the frame was made using SPHC type hollow steel material by considering mechanical properties such as tensile strength, elastic modulus, and resistance to deformation. The frame design also pays attention to ease of fabrication and efficiency of material use. Based on the results of the structural simulation, the maximum stress value was obtained at 5,599 MPa, the maximum strain at 0.0000002924, and the maximum deformation at 0.009415 mm.

A safety factor of 37.4 indicates that the frame structure is very safe and can withstand the workload well without experiencing structural failure. Therefore, the designed frame structure meets the strength and safety criteria, making it suitable for use as a support for laboratory-scale cooling system practical equipment.

Table 4. Actual Data of Observation of Frame Structure

Komponen Simulasi			
Max Stress	Max Strain	Max Displacement	Factor of Safety
5.599 N/mm ² (MPa)	0,0000002924 N.m	0,009415 mm	37,4

Cooling Unit Analysis

Based on the calculation data that has been carried out previously, the following compression, evaporation and condenser work data were obtained:

Table 5. Cooling Unit Performance Data

Kerja Kompresor	Kerja Evaporator	Kerja Kondensor
0,199 kJ (kW)	1.274 kJ (kW)	1.473 kJ (kW)

Source: Design Document

From this data, the coefficient of performance (CoP) of the cooling unit can be calculated. Referring to the ASRAE Handbook 2001, the CoP calculation for this design is as follows:

$$CoP = \frac{q_e}{q_w} = \frac{h_1 - h_4}{h_2 - h_1}$$
$$CoP = \frac{1.274}{0.199} = 6.40$$

Dimana : qe = kerja evaporasi
 qw = kerja kompresor

Table 6. Cooling Unit Performance Data
Source: Design Document

Refrigerant	Enthalpy			
	h1	h2	h3	h4
R32	kJ/kg	kJ/kg	kJ/kg	kJ/kg
	517	553.4	284.1	284.1

Based on the data presented in Table 6, it can be observed that the enthalpy value at each point in the cycle experiences significant changes according to the thermodynamic processes occurring in the cooling system. The enthalpy values at the compressor inlet and outlet indicate an increase in energy due to compression work, while on the condenser and evaporator sides, there is visible heat release and absorption that affect the overall system performance.

Therefore, the enthalpy data is an important parameter in determining the amount of compressor work, cooling capacity, and system efficiency expressed in the Coefficient of Performance (CoP). Thus, Table 6 not only presents the measurement data, but also becomes the basis for further analysis in evaluating the performance of the cooling system used. To confirm the manual calculation of CoP based on the data collection summary, calculations were carried out using online software at the link <https://tlk-energy.de/en/phase-diagrams/pressure-enthalpy> with the results of the processed calculation data which are not much different from manual calculations (Nadia & Sahim, 2012). Thus, the CoP data is confirmed and correct. The calculation results are as follows:

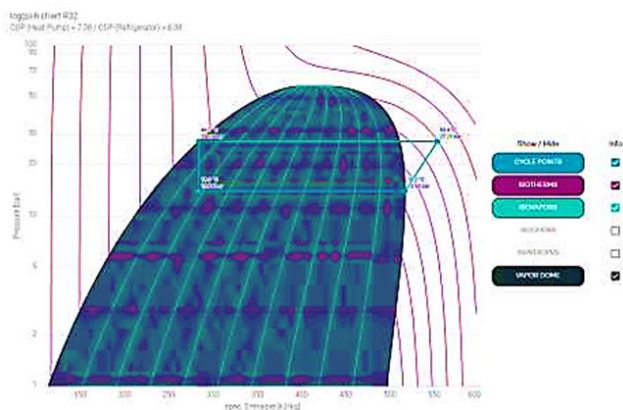


Figure 9. CoP and Log-ph diagram of the Refrigeration Unit
Source: Design Document

According to SNI Standard 03-6390-2011, the following is a COP table according to the engine type, as in the following table:

Table 7. CoP Standards

Tipe Mesin Refrigerasi	Efisiensi Minimum	
	COP	KW/TR
Split < 65.000 BTU/h	2,70	1,303
Verriable Refrigerant Value	3,70	0,951
Split Duct	2,60	1,353

Source: SNI 03-6390-2011

In addition, this design also included an EER analysis. EER stands for Energy Efficiency Ratio. The EER calculation is the result of dividing the CoP by a constant value of 0.2931. The calculation can be seen below:

$$EER = \frac{CoP}{0.2931} = \frac{6.40}{0.2931} = 21.83$$

According to the ESDM Ministerial Standard, the following are the EER criteria in the following table:

Table 8. EER Standards

EER	6.8	8.5-10	11-14	>14	20
KRITERIA EVALUASI	Sangat Buruk	Buruk	Baik	Baik Sekali	Superior
CATATAN	Exiting (Indonesia)		Market Indonesia		Jepang

Source: ESDM Ministerial Regulation

Based on the data, according to the calculations, the Refrigeration COP value is 6.40. So, when comparing the actual CoP of the cooling unit with the standard, the following results are obtained:

Table 9. Results of the CoP Design

Actual CoP	Standard	Conclusion
6.40	2.70	Qualified (Good)

Source: Design Document

However, a phenomenon was found where the indication value on the pressure gauge which was designed to determine the compression pressure (Discharge) and fluid pressure during evaporation (Suction) did not show a value that corresponded to the reference and manual calculations of the design data (actual temperature of condensation release and actual temperature of the fluid during evaporation).



Figure 10. Discharge Pressure Reading Phenomenon in the Design
Source: Design Document



Figure 11. Suction Pressure Reading Phenomenon in Design
Source: Design Document

This will be a challenge in the future so that this design can be analyzed and further research can be carried out on this phenomenon which is possibly caused by connection factors and determination of the tee joint in the cooling fluid channel.

Cooling Load Analysis

A cooling load analysis is performed to determine the amount of heat the cooling system must absorb to maintain the room temperature within the planned range. This calculation serves as the basis for determining the capacity and performance of the cooling system. This ensures the cooling system design meets testing requirements.

Table 10. Design Cooling Capacity

Cooling Capacity	Total Cooling Load	Conclusion
1,335 kW	1,150 kW	The cooling capacity is still greater than the cooling load with a cooling load percentage of 86.14% of cooling capacity

Source : Design Document

Frame Structure Analysis

The frame structure analysis was conducted to ensure that the frame is able to withstand the workload safely and stably during the operation of the tool. The analysis was conducted using a simulation method based on Finite Element Analysis (FEA) by considering the mechanical properties of the material and loading conditions. Based on the simulation results, the maximum stress was obtained at 5,599 MPa, the maximum deformation was 0.009415 mm, and the strain was very small. The value of the safety factor (Factor of Safety).

A value of 37.4 indicates that the frame structure is in a very safe condition and far from the material failure limit. Thus, the frame design used has met the strength and stiffness criteria, making it suitable for use as a support for a laboratory-scale cooling system.

Table 11. Maximum Stress and Design Safety Factor

Max Stress	Yield Strength	Kesimpulan
5.6 N/mm ² (MPa)	209.6 N/mm ² (MPa)	Nilai tegangan sangat kecil dan struktur dapat melayani (Aman)
FoS	Min FoS	Kesimpulan
37.4	2	Nilai FoS aktual hasil simulasi sudah melampaui batas target sehingga rangka sangat memenuhi factor keamanan

Source : Design Document

CONCLUSION

Based on the results of the design, analysis, and testing that have been carried out, it can be concluded that the developed cooling system is able to meet the cooling load needs of the test room. The resulting cooling capacity is 1,335 kW, higher than the load requirement of 1,150 kW, so that the system is declared able to work optimally. In addition, the actual Coefficient of Performance (COP) value of 6.40 and Energy Efficiency Ratio (EER) of 21.83 indicate good system performance and has met applicable standards.

The simulation analysis of the frame structure yielded a maximum stress of 5.6 N/mm², with a safety factor of 37.4. This demonstrates the frame's excellent strength and safety in supporting the cooling system load. Overall, the designed laboratory equipment meets performance and safety requirements, making it suitable for use as a laboratory-scale learning tool.

Further development is needed to improve the accuracy and validation of the results, both through advanced simulations using Computational Fluid Dynamics (CFD) methods and direct experimental testing. Furthermore, the development of practical modules and technical instructions for using the tool is necessary to optimally support the learning process. Future design developments can also focus on improving system efficiency and refining the tool's features..

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