ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MECHANICAL DESIGN AND ANALYSIS OF MOBILE PRE-CONDITIONED AIR (PCA) UNIT FOR A TACTICAL UNMANNED COMBAT AERIAL VEHICLE

M.Sc. Thesis by

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ANKARA

MECHANICAL DESIGN AND ANALYSIS OF MOBILE PRE-CONDITIONED AIR (PCA) UNIT FOR A TACTICAL UNMANNED COMBAT AERIAL VEHICLE

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"MECHANICAL DESIGN AND ANALYSIS OF MOBILE PRE-CONDITIONED AIR (PCA) UNIT FOR A TACTICAL UNMANNED COMBAT AERIAL VEHICLE"** completed by **FURKAN EMEKSİZ** under the supervision of **PROF. DR. HÜSEYİN CANBOLAT** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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2023, 9 August **Furkan Emeksiz**

MECHANICAL DESIGN AND ANALYSIS OF MOBILE PRE-CONDITIONED AIR (PCA) UNIT FOR A TACTICAL UNMANNED COMBAT AERIAL VEHICLE

ABSTRACT

Unmanned aerial vehicles (UAVs), used by the air forces of many countries today, possess capabilities for reconnaissance, surveillance and precision strikes. Unmanned combat aerial vehicles (UCAVs) provide tactical advantages for air forces in almost every region of the world. However, their sensitive electronic components require appropriate thermal management for critical tasks during ground testing and maintenance activities. In general, Pre-Conditioned Air (PCA) units are responsible for cooling, heating and conditioning the desired environment and delivering conditioned air to relevant spaces such as aircraft, military or medical shelters and command centers. The FE-PCA device is a portable, economical, durable and efficient solution, designed with a special configuration where system components are integrated onto a sturdy steel chassis. This thesis consists of the establishment, design, and analysis of a climate control system utilizing an ideal vapor compression cooling cycle with a mobile PCA unit developed for an UCAV, addressing the identified needs. The designed mobile FE-PCA device aims to effectively provide cooling or if necessary, heating to the aircraft without relying on external sources. Its primary objective is to ensure the optimal ambient temperature for electronic devices within the aircraft. Additionally, when used in conjunction with a ground power unit (GPU) during ground tests and maintenance activities, it eliminates the need for the aircraft engine to run, resulting in fuel savings and ensuring the job safety of technicians. The conducted system design, mechanical design and analysis have resulted in a next-generation mobile PCA unit with a cooling capacity of 21.6 KW. With the designed unit, UCAVs will be able to reliably perform critical attacks, coordination and intelligence reconnaissance missions.

Keywords: Air force, unmanned combat aerial vehicle, mobile PCA unit, air conditioning, mechanical design.

BİR TAKTİK SİLAHLI İNSANSIZ HAVA ARACI İÇİN MOBİL ÖN ŞARTLANDIRILMIŞ HAVA ÜNİTESİNİN MEKANİK TASARIM VE ANALİZİ

ÖZ

Günümüzde bir çok devletin hava kuvvetleri tarafından kullanılan insansız hava araçları, keşif, gözetleme ve hassas vuruş kabiliyetlerine sahiptirler. Silahlı insansız hava araçları dünyanın neredeyse her bölgesinde hava kuvvetleri için taktiksel avantaj sağlarlar. Ancak hassas elektronik aksamları yer testleri ve bakım-onarım faaliyetleri sırasında kritik görevler için uygun yer termal yönetimine ihtiyaç duyarlar. Genel manasıyla PCA(Ön şartlandırılmış hava) ünitelerinin amacı istenilen ortamı soğutmak, ısıtmak ve şartlandırılmış havayı, hava araçları, askeri veya tıbbi barınaklar ve komuta merkezleri gibi ilgili ortamlara vermekten sorumludur. FE-PCA aracı taşınabilir,ekonomik,dayanıklı ve tasarruflu çözüm sunarak çeşitli ortam ve hava koşullarında kullanılabilen,sistem komponentlerinin sağlam bir çelik şase üzerine entegre edildiği özel bir tasarıma sahiptir. Bu tez belirlenen ihtiyaçlar doğrultusunda bir silahlı insansız hava araçı için geliştirilen mobil PCA ünitesinin ideal buhar sıkıştırmalı soğutma çevrimi ile iklimlendirme sisteminin kurulması, tasarımı ve analizinden oluşmaktadır. Tasarlanan mobil FE-PCA aracı ile amaçlanan başka kaynaklara ihtiyaç duymadan etkili bir şekilde hava aracına soğutma veya ihtiyaç olması halinde ısıtma sağlayarak hem hava aracı içerisindeki elektronik cihazlar için optimum ortam sıcaklığını sağlamak, hem de yer testleri ve bakım onarım faaliyetleri sırasında bir yer güç ünitesi (GPU) ile birlikte kullanılmasıyla uçak motorunun çalışmasına gerek duyulmamasından dolayı yakıt tasarrufu sağlanması ve aynı zamanda çalışan teknisyenin iş güvenliğini sağlamaktır. Yapılan sistem tasarımı, mekanik tasarım ve analiz sonucunda 21.6 KW soğutma kapasitesine sahip yeni nesil bir mobil PCA ünitesi ortaya çıkmış olup, tasarlanan araç sayesinde silahlı insansız hava araçları görev açısından kritik saldırıları, koordinasyonu ve istihbarat keşiflerini güvenilir bir şekilde gerçekleştirebileceklerdir.

Anahtar Kelimeler: Hava kuvvetleri, silahlı insansız hava aracı, mobil PCA ünitesi, iklimlendirme, mekanik tasarım

CONTENTS

NOMENCLATURE

Abbreviations

ASTM	American Society for Testing and Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
COP	Coefficient of Performance
CPU	Central Process Unit
EPDM	Ethylene Propylene Diene Monomer
FEA	Finite Element Analysis
GPU	Ground Power Unit
HVAC	Heating Ventilation and Air Conditioning
IP	Ingress Protection
ISR	Intelligence Surveillance and Reconnaissance
PCA	Pre Conditioned Air
TIG	Tungsten Inert Gas
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle

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CHAPTER 1

INTRODUCTION

PCAs (Pre-Conditioned Airs) have critical importance for aircraft. PCA units provide fresh conditioned air at optimal temperature inside the aircraft while it is parked. Additionally, an aircraft contains numerous electronic devices and it is necessary to maintain sufficient temperature inside the aircraft to ensure the smooth operation of these electronic devices [1]. The FE-PCA unit not only maintains avionics at the optimal temperature in an aircraft but also allows unmanned combat aerial vehicles to perform maintenance and ground tests without the need to start their own engines, thanks to its use in conjunction with GPUs (Ground Power Units). This enables important operations to be carried out smoothly. Furthermore, its portability in terms of mobility allows it to be used in desired locations and provides an advantage in terms of rapid deployment for emergency situations.

Mobile FE-PCA unit is a portable electrical unit designed to serve unmanned combat aerial vehicles. It can operate using grid electricity or external power sources in the area where it is deployed. The unit consists of cooling system components and heating resistance, providing cooling, heating and climate control features. The system used in the unit is a vapor compression refrigeration cycle and employs the environmentally safe R-410a refrigerant gas. The system ensures that the aircraft is maintained at the optimal temperature while on the ground. Temperature control of the environment is achieved through thermostat regulation.

The FE-PCA unit provides a continuous and reliable operational service with minimal maintenance requirements, ensuring a long service life. It is specifically designed considering the climate requirements of a particular unmanned combat aerial vehicle. This work provides a general overview of climate control systems and various PCA units under the literature section. It then proceeds to give general information about the components used in the refrigerant flow system, followed by component selection and calculations. The design is carried out based on component placement and finally, the analysis outputs of the unit are included.

1.1 Literature Research

1.1.1 PCA Units

Pre-Conditioned Air (PCA) is a term related to HVAC (Heating, Ventilation and Air Conditioning) terminology. In HVAC terminology, a conditioned space refers to an area that needs to be cooled or heated, separate from the external atmosphere [2]. Air conditioning is the process of taking in outside air, filtering out any impurities and altering the temperature and humidity to achieve and maintain the desired atmosphere. As the outside air passes through the air conditioning system, its characteristics change, impurities are removed and its temperature decreases. The air that is ready to enter the conditioned space is referred to as "preconditioned air". The layout of a PCA unit in the field is shown in Figure 1.1.

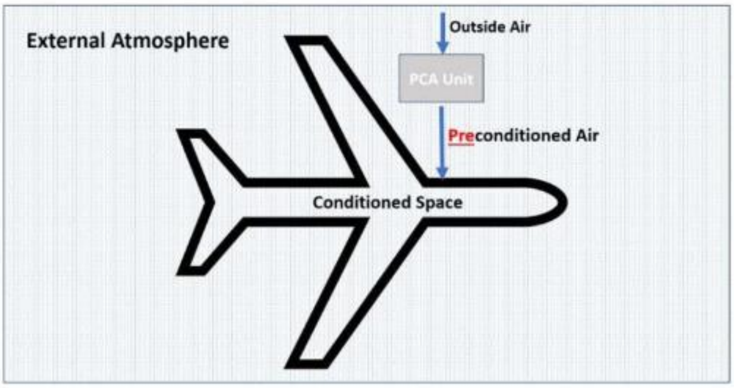


Figure 1.1 Placement of PCA unit for an aircraft

The interior of an aircraft is a conditioned space and the air ducts supply conditioned air while the unmanned combat aerial vehicle (UCAV) is in flight. The air received is already conditioned because it is separate from the UCAV's own cooling system. Therefore, the air supplied by the Pre-Conditioned Air (PCA) Unit is already conditioned and is referred to as "pre-conditioned" air.

In short, the PCA unit provides conditioned air to the aircraft and from the perspective of the aircraft, this is referred to as pre-conditioned air. An example of a portable mobile PCA unit is shown in Figure 1.2.

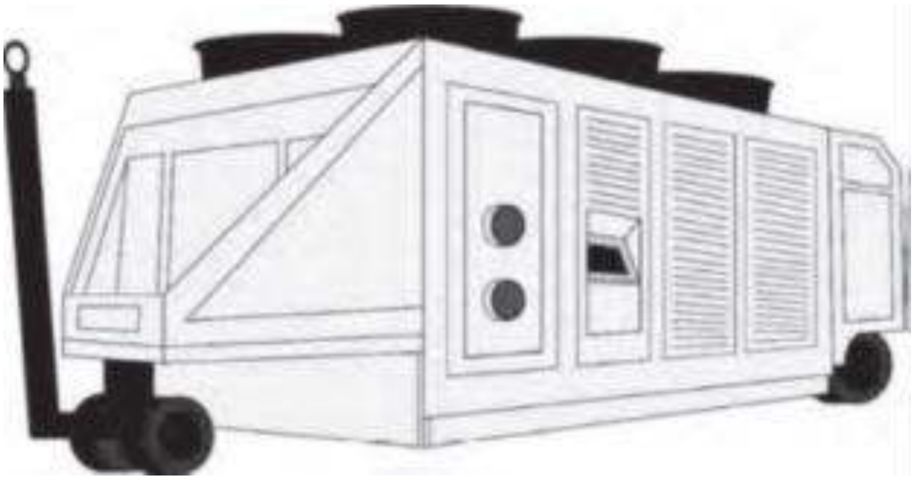


Figure 1.2 An example of a portable mobile PCA unit [3]

1.1.2 The Necessity of Using a Pca Unit

High-tech electronic devices in the avionics compartment of unmanned combat aerial vehicle tend to overheat [4]. This issue can be observed in data center cooling for aircraft avionics, high-tech military electronic devices or command center cabins, negatively impacting the electronic equipment. To mitigate this problem and maintain optimal operating conditions, proper thermal management in suitable locations is necessary. Failure to do so can result in the malfunctioning of cameras and radars in intelligence, surveillance and reconnaissance (ISR) systems, leading to mission failure.

Tactical unmanned combat aerial vehicle cool their onboard electronic systems during flight using their own air ducts. However, while on the ground, they rely on PCA (Pre-Conditioned Air) and GPU (Ground Power Unit) to supply power, cool the cabin and meet energy and climate control needs when required. Fuel is one of the biggest costs for an aircraft [5]. Reducing fuel usage lowers costs and produces fewer emissions. With the help of these units, during ground tests and maintenance, the aircraft's own engine does not need to be running as both climate control and energy requirements are met. This leads to significant benefits in terms of cost and emission reduction associated with military operations, addressing both economic and environmental factors. Additionally, the use of PCA (see Figure 1.3) units plays a role in reducing air pollutants and greenhouse gas emissions.

Figure 1.3 An operational view of a mobile PCA unit

Due to the various reasons mentioned, when an aircraft reaches its landing area, the aircraft engines are shut down. It is necessary for the air conditioning system to continue operating during maintenance, repair and ground testing activities. In cases requiring maintenance and repair, the Pre-Conditioned Air is activated. In this scenario, technicians perform ground tests and maintenance activities to ensure the unmanned aerial vehicle's controls and prepare it for flight.

1.1.3 Usage Areas and Climatic Factors of PCA Units

Since militaries operate worldwide, aircraft travel to various locations and encounter both extremely hot and cold climates. Therefore, the environmental conditions that a PCA unit will face can vary greatly. Unmanned combat aerial vehicles need to withstand extreme temperatures and continue operating under different environmental conditions. While PCA units are typically used in moderate environments, they are expected to perform in more extreme conditions due to the nature of operational missions.

Cooling demand is of critical importance in hot climates, especially during the summer months. On the other hand, heating demand may take priority in extremely cold climates. Therefore, the unit should have a structural and system design that allows it to operate in various climate conditions. In this regard, the designed PCA unit has the ability to operate in different temperature ranges.

The FE-PCA unit is designed to withstand different elements and climatic conditions with its steel chassis and corrosion-resistant coatings and paint protection. This design ensures its long lifespan and high performance. Due to its specific design for the requirements of unmanned combat aerial vehicles, with necessary system and design modifications, the FE-PCA unit can also be used in various environments such as military shelters, medical facilities, mobile emergency response units and military command centers.

1.1.4 Types of Pre-Conditioned Air (PCA) Units Based on Power Source and Structure

In terms of power source, Pre-Conditioned Air (PCA) units can be divided into two types:

1.1.4.1 Engine Driven Pre-conditioned Air (PCA) Unit

Engine-driven Pre-Conditioned Air (PCA) units are typically powered by an internal combustion engine, usually a diesel engine. The engine runs a generator to produce the electricity needed to power the cooling compressors of the PCA unit.

These units are traditional systems that have been used for a long time. Engine-driven PCA units are driven directly by the engine, which powers the cooling compressor, eliminating the need for an electric generator. In essence, an engine-driven PCA unit is simply an air conditioner driven by an internal combustion engine.

1.1.4.2 Electric Pre-conditioned Air (PCA) Unit

Electric Pre-Conditioned Air (PCA) units operate with grid power supply. They can draw electrical power from any nearby power source available in the vicinity of the aircraft. All components and circuits are powered by this electrical supply.

Electric PCA units have no emissions and are generally more energy-efficient compared to engine-driven PCA units. They are also preferred for their lower operating noise levels compared to engine-driven units. As a result, electric PCA units utilize power from the grid source instead of generating power in the field like diesel engine-driven PCA units.

In addition to the power source, there are three types of pre-conditioned air (PCA) units based on installation types:

- Bridge mounted pre-conditioned air (PCA) units

As the name suggests, bridge-mounted PCA units are mounted on jet bridges (see Figure 1.4). With the help of a special mounting frame and supports, they are installed under one of the tunnels of the bridge. In some configurations, the PCA unit can also be mounted on top of the bridge instead of underneath. Generally, bridge-mounted PCA units are electric PCA units. Engine-driven PCA units are not mounted under the bridge as they tend to generate unwanted vibrations that can affect the integrity of the jet bridge.

Figure 1.4 Bridge mounted PCA units generally hang under the bridge [6]

- Fixed above-ground preconditioned air (PCA) units

If it is not desired to mount PCA units under the bridge, they can be fixed to the ground (see Figure 1.5). These types of PCA units are mounted to the aircraft stand on the ground and typically operate on electricity. The conditioned air is supplied from the PCA unit to the aircraft through one of the following methods:

  - Transporting conditioned air from the PCA unit to the aircraft through an underground duct using a flexible hose placed within a trench on the apron.
  - Using a flexible hose that connects to the aircraft via a channel, which starts from the PCA unit and extends along the jet bridge tunnel, collecting the conditioned air from the PCA unit mounted under the jet bridge.

Figure 1.5 Ground-mounted PCA unit [7]

- Mobile pre-conditioned air (PCA) units

Mobile PCA units, as the name suggests, are PCA units that can be transported to any desired location or towed by towing vehicles. They are equipped with all components mounted on a chassis. Their mobility allows them to be easily moved to the desired location and provides greater flexibility to serve different aircraft throughout the day.

Thanks to this increased mobility, it allows for easier and faster handling of maintenance, repairs and equipment issues. Mobile PCA units do not have any installation costs, unlike fixed on-ground PCA units and bridge-mounted PCA units. For example, if a PCA unit malfunctions, a mobile PCA unit can be quickly transported to the area as a backup to continue providing PCA support to the arriving aircraft. This helps ensure the continuity of operations. Fixed or bridge-mounted PCA units do not have the possibility to be moved to another stand where a PCA unit is needed.

Moreover, Mobile PCAs simplify the movement planning of aircraft and streamline ground support operations, as they can be easily moved from one aircraft to another. In addition to reducing the risk of accidents on the airfield, they also help reduce operational costs by saving fuel consumed by towing vehicles, as they can be moved independently. The mobile PCA unit has been chosen due to its ease of use and the mentioned advantages in the design. More detailed design information can be accessed within the scope of the thesis.

1.1.5 Maintenance, Service and Spare Parts

Routine maintenance, breakdown maintenance and troubleshooting are important aspects of a PCA unit. Maintenance and service are fundamental values in product support and are crucial for continuity. Hazards encountered during operations occasionally reveal maintenance needs. Maintenance and repair services are required to ensure the proper and smooth functioning of all PCA components. In the event of a malfunction, PCA units need to be restored and repaired in the field. Mobile PCA units have a significant advantage due to their ability to be transported to any location without being hindered by space constraints. Additionally, mobile PCA units do not incur any installation costs.

Service technicians need to comprehensively troubleshoot the non-functioning issue of the PCA and identify which components need to be replaced or repaired, if any. They should conduct a thorough examination of the components in the field and then test all functions to ensure that the system is working properly.

In after-sales services, it is essential to provide the following: initial training, remote troubleshooting support, on-site technical service support and spare parts support for the components needed by the user. Through the user manual, detailed support regarding PCA's, including product maintenance and safety practices, is also provided to the users.

1.1.6 Ground Power Unit (GPU)

While an aircraft is in the air, it generates all electrical power through its own engines. This means that the aircraft engine not only produces thrust to enable flight but also serves as a power plant during the flight, supplying power to all critical and auxiliary systems.

Aircraft require these power units to continuously supply power because during maintenance, repairs or prior to the next flight, it is necessary to verify functionality and conduct various system checks on the ground. This involves testing all control systems, flight equipment, radar, electric motor-driven mechanisms, cockpit and lighting systems, among others. Therefore, they rely on these power units to ensure continuous power supply [3].

When an aircraft lands, it keeps one of its engines running to provide sufficient thrust for taxiing to the desired area and to supply power to all electrical systems. Once the aircraft reaches the designated area and comes to a stop, the requirement for thrust diminishes, but the need for electrical power remains. Whether it's for aircraft maintenance, ground tests, or the next flight, the aircraft still relies on electrical power. A TLD brand ground support unit is shown in see Figure 1.6.

Figure 1.6 TLD GPU-28-CUP diesel ground power unit

We discussed the need to keep many electrical and electronic systems operational for a technician to prepare an aircraft for the next flight, perform maintenance and repairs and ensure technical checks. When an aircraft arrives at its parking area, there is usually a significant amount of activity around it and it is generally not desirable to keep the aircraft engines running. This is because the aircraft engines, which generate power by burning fuel, create excessive noise for technicians working on various tasks around the aircraft. It also incurs additional costs and produces carbon emissions, which poses a safety hazard [2].

In summary, keeping the aircraft engines running on the ground would hinder most ground support activities. Regulatory authorities in aviation have a strict approach to both occupational health and safety and environmental protection [8]. Due to factors such as occupational health and safety, cost impact and carbon dioxide emissions, the use of GPU (Ground Power Unit) and PCA (Pre-Conditioned Air) units is recommended, encouraged and sometimes mandated.

CHAPTER 2

REFRIGERANT SYSTEM AND COMPONENTS

2.1 Principles of the Ideal Vapor Compression Refrigeration Cycle

HVAC stands for heating, ventilating and air conditioning. When it comes to HVAC systems, there are many options available, but they all work in a similar way. They take in clean air and use a mechanical ventilation system to heat or cool it to the desired temperature. HVAC units can also improve air quality through air purifiers that capture particles as small as bacteria, spores and viruses. Air conditioning, on the other hand, is the general term for systems that perform tasks such as temperature control, air circulation control and air purification. In other words, it is the general term for equipment that ensures the air in a desired area is at an optimal temperature. When the temperature is high, heat is extracted to lower the temperature, which is called "cooling". Conversely, when the temperature is low, heat is provided to increase the temperature, which is called "heating".

Cooling can be defined as the transfer and displacement of heat. Substances or fluids that extract heat from a substance or environment to perform the cooling process are referred to as refrigerants. In ideal vapor compression refrigeration systems, they carry out the task of heat transfer. There are four main components in a cooling system: evaporator, condenser, compressor and expansion valve.

The working principle of vapor compression refrigeration is as follows: In the cycle, the condenser is an heat exchanger that releases heat to the surroundings, causing the compressed hot gas to condense into a liquid state. The liquid refrigerant then enters the expansion valve, which restricts the flow of the fluid through a small orifice, resulting in a pressure drop. As a result, the boiling point of the refrigerant decreases, making it easier for it to evaporate. When the refrigerant evaporates, it absorbs heat from its surroundings, thereby cooling the environment. The location where this evaporation occurs is called the evaporator. The refrigerant then returns to the compressor to complete the cycle. The refrigerant is reused to absorb heat and transfer it to another location [9]. The ideal vapor compression refrigeration cycle and the T-s diagram are given in Figure 2.1 .

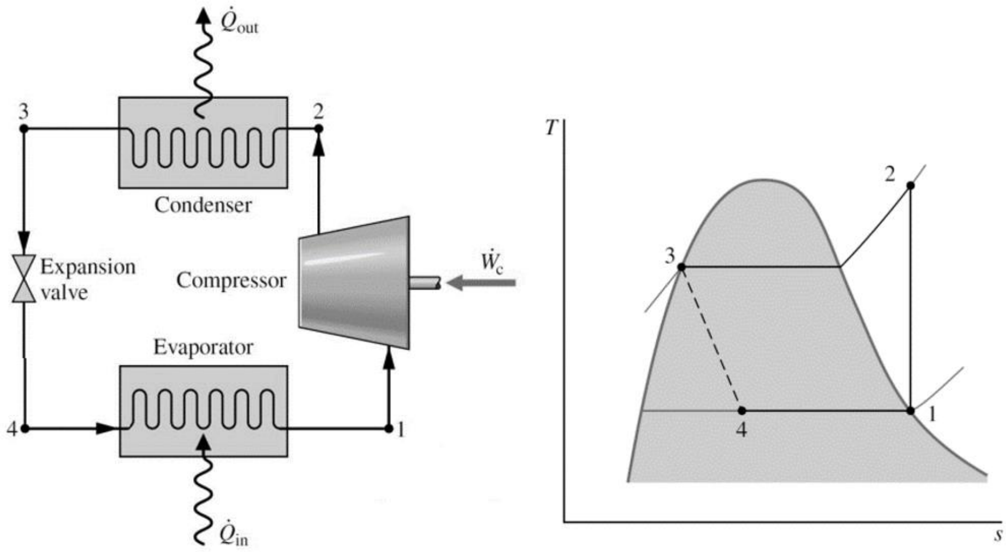


Figure 2.1 Ideal vapor compression refrigeration cycle and T-s diagram

In the ideal vapor compression refrigeration cycle, during the phase change in the direction of 1-2, the refrigerant enters the compressor as saturated vapor at point 1 and is adiabatically compressed to a very high temperature and condenser pressure at point 2. From point 2, the refrigerant in the superheated vapor phase enters the condenser and releases heat to the surroundings, exiting the condenser as saturated liquid at point 3. At point 3, the refrigerant in the saturated liquid phase passes through the expansion valve, causing its pressure to drop to the evaporator pressure, reaching point 4. In the direction of 3-4, the temperature of the refrigerant decreases significantly below the ambient temperature, entering the evaporator in this state. In the evaporator, the refrigerant absorbs heat from the surroundings, entering the compressor as saturated vapor to complete the cycle. The P-h diagram of the ideal vapor compression refrigeration cycle is shown in Figure 2.2.

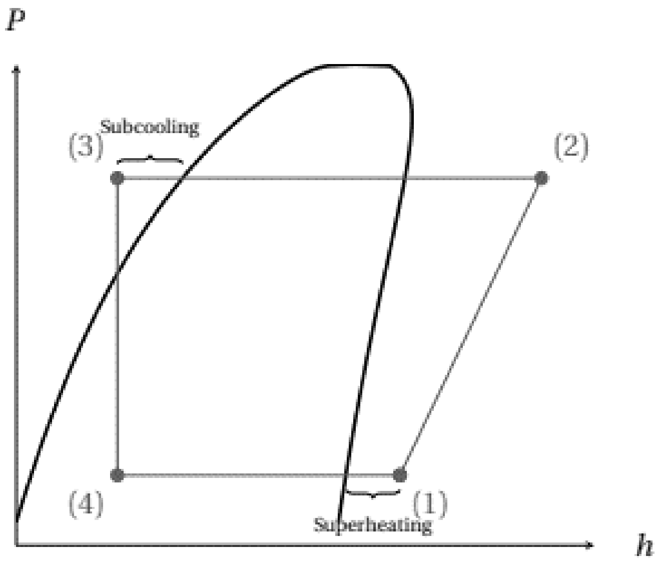


Figure 2.2 Pressure-enthalpy diagram for a basic refrigeration cycle [10]

One crucial aspect to consider in the cooling cycle is the heat transfer rate. Cooling systems often utilize materials with excellent thermal conductivity, such as copper and aluminum. In other words, heat can easily flow through these materials. Increasing the heat transfer surface area is another method to enhance heat transfer. Cooling system heat transfer components, such as air-cooled condensers and evaporators are commonly constructed using copper tubes and aluminum fins. Subsequently, fans are used to facilitate a greater flow of air through the fins. Using materials with high thermal conductivity and maximizing the heat transfer surface area are effective ways to improve heat transfer in cooling systems.

2.2 Cooling System Components

Air conditioners consist of four main components and auxiliary equipment, namely compressor, evaporator, condenser and expansion valve. The main components of the designed cooling system are listed below:

- Compressors
- Evaporator
- Condenser

- Expansion Valve
- Refrigerant Gas
- Axial Fan
- Centrifugal Fan
- Liquid Receiver
- Filter Drier
- Sight Glass
- Rezistans (Serpentine)
- Filter
- Thermostat
- Copper pipes
- Joining Elements

2.2.1 Air Conditioner Compressors

Compressors, along with the evaporator, condenser and expansion valve, are essential components of traditional cooling systems and are also known as the heart of air conditioning units. The air conditioning compressor is a mechanical component of the air conditioning system that enables the flow of refrigerant in a cycle. It functions as a vapor pump in the system [11].

As shown in the scroll compressor (see Figure 2.3), the compressor has a refrigerant inlet line (low side) and a refrigerant outlet line (high side). Through the circulation of the refrigerant, heat transfer occurs from the cold source to the hot source with the help of compressors, creating a pressure difference between the suction pressure and the discharge pressure [12]. The compressor draws in the vapor of the refrigerant from the suction line and compresses it, transforming it into high-temperature and high-pressure vapor.

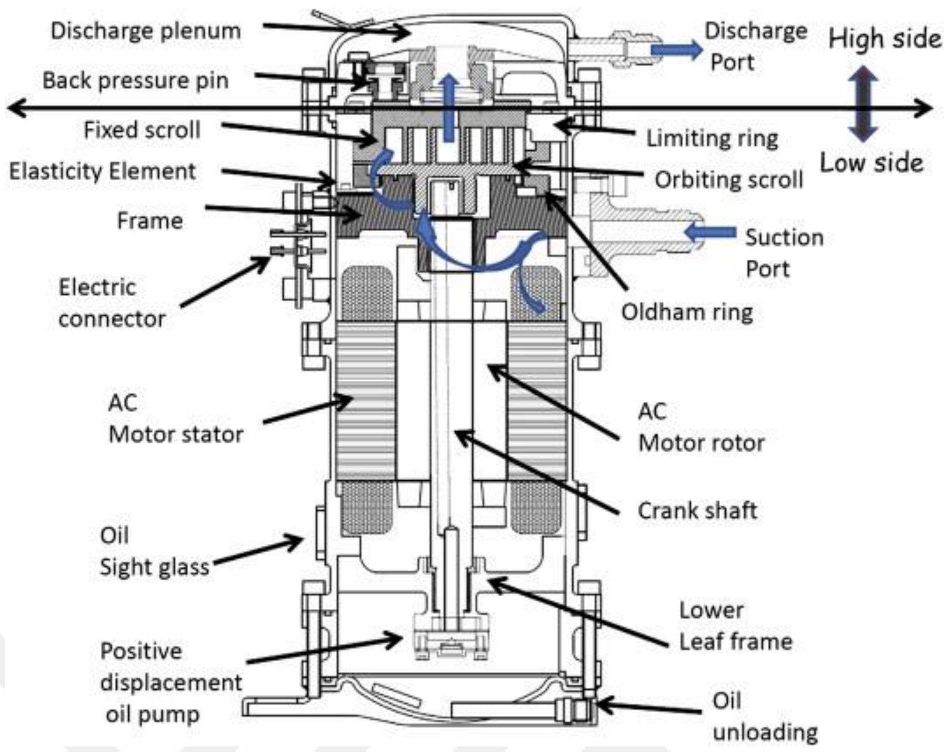


Figure 2.3 Scroll compressor parts [13]

Compressor technology continues to evolve and there are many different types of compressors available today, including:

• Piston compressors
• Rotary compressors
• Centrifugal compressors
• Screw compressors
• Scroll compressors

In an ideal compressor; It is desired that the rotation moment at the first start-up should be as low as possible, its life should be long by maintaining its safety and security under different operating conditions, vibration and noise levels should exceed certain levels at partial and full loads and under different conditions, it should be able to provide unit cooling value by consuming less power and the cost should be as low as possible [14].

Therefore, the scroll compressor has been selected as the most suitable compressor type for use in the system. A scroll compressor is a compressor that utilizes two or more spirals to compress the working fluid (see Figure 2.4). These spirals move in a circular motion instead of the up and down motion of a piston compressor. One of the spirals is a vibrating rotary spiral, while the other spiral remains fixed. When the fluid enters the compressor, it becomes trapped between the spirals and compression occurs as the rotary spiral rotates. The scroll compressor operates on the principle of positive displacement. The moving scroll rotates 180° relative to the fixed scroll, creating a meshing effect between the scrolls.

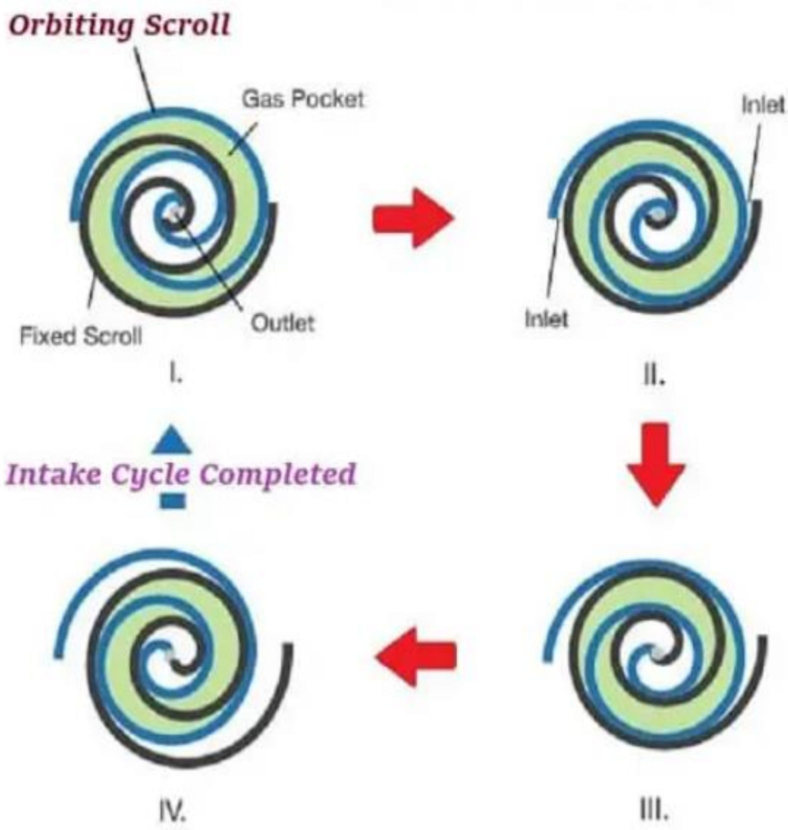


Figure 2.4 Scroll compressor spiral diagram

Scroll compressors operate quietly and smoothly. They are widely used in HVAC systems due to their higher efficiency and reliability compared to piston compressors.

2.2.2 Evaporator

Evaporators, also known as evaporative coils (see Figure 2.5), are equipment based on the principle of extracting heat from the surrounding environment as the fluid inside them evaporates. They are widely preferred in cooling systems due to their versatility in application. Cooling systems cannot be imagined without evaporators, as they are structurally similar to condensers. The primary function of an evaporator is to vaporize the liquid circulating in the system channels from the environment that requires cooling. Additionally, it also serves the purpose of drawing in the surrounding air. Depending on the supply of refrigerant, operating conditions, circulation method of the liquid or air to be cooled, control type of the refrigerant and the specific application, evaporators can be found in various constructions and sizes [15].

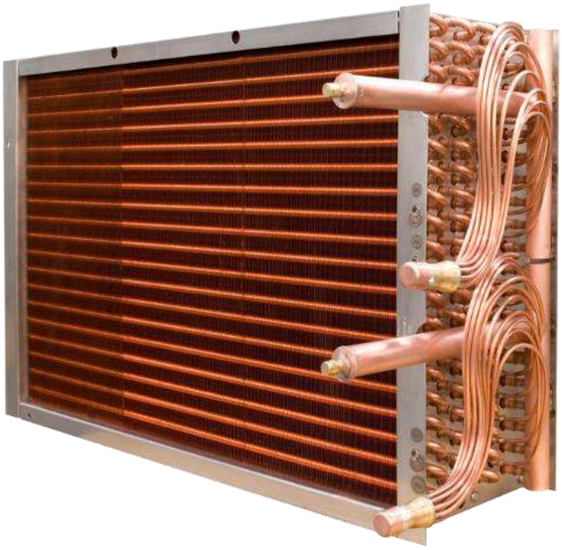


Figure 2.5 An evaporator appearance

When air is passed through the evaporator by means of a blower in an HVAC system, the refrigerant undergoes a phase change and transitions into a gas state. The evaporating refrigerant extracts heat from the surrounding environment where the evaporator is located and the resulting cold air is delivered to the desired area. The evaporator coil, which is a fundamental component of most HVAC systems, contains the cooled refrigerant that absorbs heat from the system. As the heat is absorbed, the refrigerant undergoes a transition from liquid to gas and moves towards the compressor. Subsequently, the heated refrigerant is transported to the condenser coils externally, where it is dissipated into the surroundings. In Figure 2.6, depicts a schematic representation of an example evaporator and illustrates the flow directions.

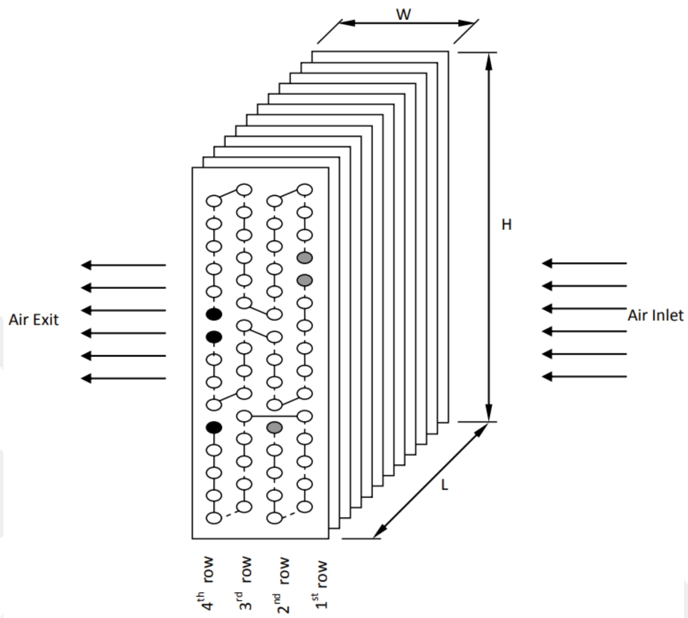


Figure 2.6 Evaporator configuration

The evaporator shown in the figure consists of four rows and three circuits [16]. Advanced techniques are employed in the circuit arrangement of evaporators for both the refrigerant and air side. The specifications and physical dimensions of the evaporator to be used in the system are determined based on the system requirements.

2.2.3 Condenser

Condensers are essential components of cooling systems that facilitate the conversion of high-pressure and high-temperature gaseous refrigerant into liquid form by dissipating heat to the external environment. Additionally, a compact condenser is a specialized type of heat exchanger designed to achieve a large heat transfer surface area per unit volume. The refrigerant vapor releases the heat it has absorbed from the evaporator and compressor to the air through the condenser surface at high pressure and temperature. In a cooling system, the total heat extracted in the evaporator and the heat added to the refrigerant by the compressor is ultimately expelled to the outside through the condenser. The condenser removes the heat from the vapor first to the walls of the condenser tubes and then transfers it to the surrounding environment (see Figure 2.7).

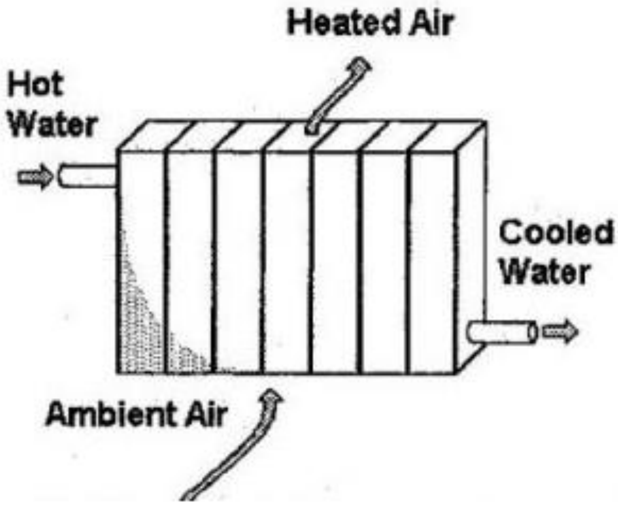


Figure 2.7 Heat transfer processes in the condenser

There are generally three different types of condensers:

- Air-cooled condenser
- Water-cooled condenser
- Evaporative condenser

For the designed system, an air-cooled condenser type has been selected. An air-cooled condenser is a type of condenser where the cooling cycle involves the condensation of the refrigerant vapor by means of air. Heat exchange in air-cooled condensers occurs in three stages: heat rejection, refrigerant condensation and subcooling. In the heat rejection process, only 5% of the condenser area is utilized. The majority of the condenser area, approximately 85%, is dedicated to the primary task of refrigerant condensation. Depending on the condenser design, about 10% of the condenser area is utilized for subcooling [17]. In air-cooled condensers, it is common to use a liquid receiver to collect and store the condensed refrigerant from the condenser. This is done to avoid using the useful condenser area for liquid storage. The heat transfer capacity of a condenser is influenced by four factors: the material used in its construction, the contact area between the condenser surface and the condensing medium, the temperature difference between the condensing medium and the refrigerant and the flow rate of the condensing medium. Different materials have different heat transfer capabilities, allowing for the design of condensers with different sizes but the same capacity. Aluminum is commonly used in the production of these condensers due to its low cost and lightweight nature. A typical wire and tube type condenser is shown (see figure 2.8).

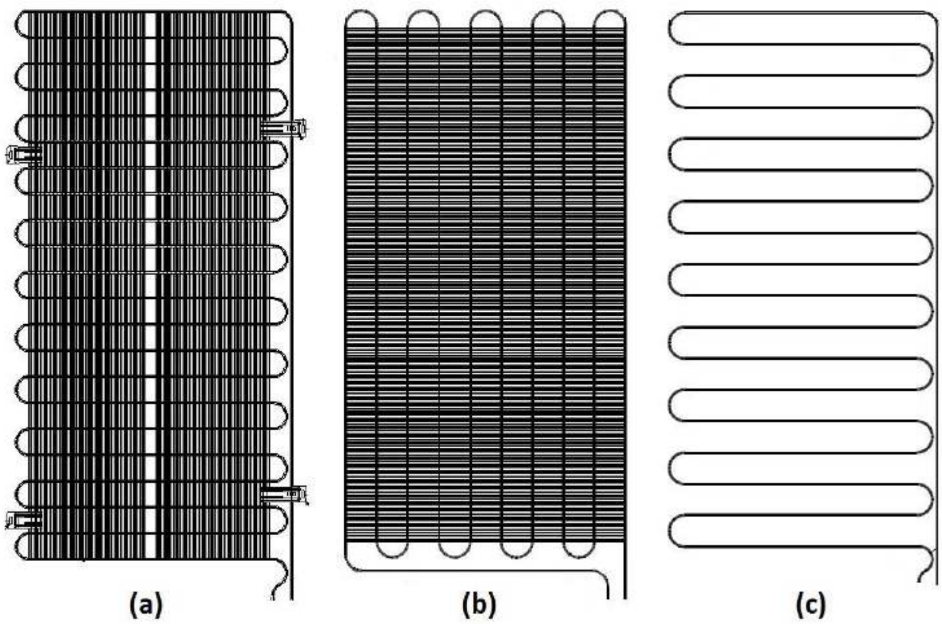


Figure 2.8 A typical wire and tube type condenser; a: horizontal tubes, b: vertical tubes, c: shortened horizontal tubes [18]

Air-cooled condensers utilize air as the cooling medium. Due to the typically low circulation of air around the condenser under normal conditions, it is necessary to have a large condensing area. Condensers can be constructed with fins added to copper, steel or aluminum tubes to enhance heat transfer.

2.2.4 Expansion Valve

In refrigeration systems, an expansion valve or a similar component is used to reduce the pressure of the refrigerant gas. Despite its simple structure with no moving parts, the expansion valve (see Figure 2.9) is the main control device of the refrigeration system.

Figure 2.9 An example of an expansion valve

This valve takes the refrigerant from the dryer and has adjustable openings to allow a specific amount of refrigerant to flow through the system for proper cooling. The system is divided into two sides: the high-pressure side and the low-pressure side. The high-pressure side starts at the compressor and ends at the expansion valve. The low-pressure side starts at the expansion valve and ends at the compressor. These two components have similar but opposite tasks of increasing and decreasing pressure.

The component after the expansion valve is the evaporator unit and the adjustment level in the expansion valve is determined based on temperature detection in this part. The expansion valve also has the capability to determine the amount of refrigerant required to provide vapor to the evaporator unit [19]. During the flow of refrigerant from the evaporator unit to the compressor, pressure should be taken into consideration; otherwise, problems and cracks may occur in the compressor unit. The expansion valve consists of a diaphragm and a spring inside a tube on the cylinder body (see Figure 2.10).

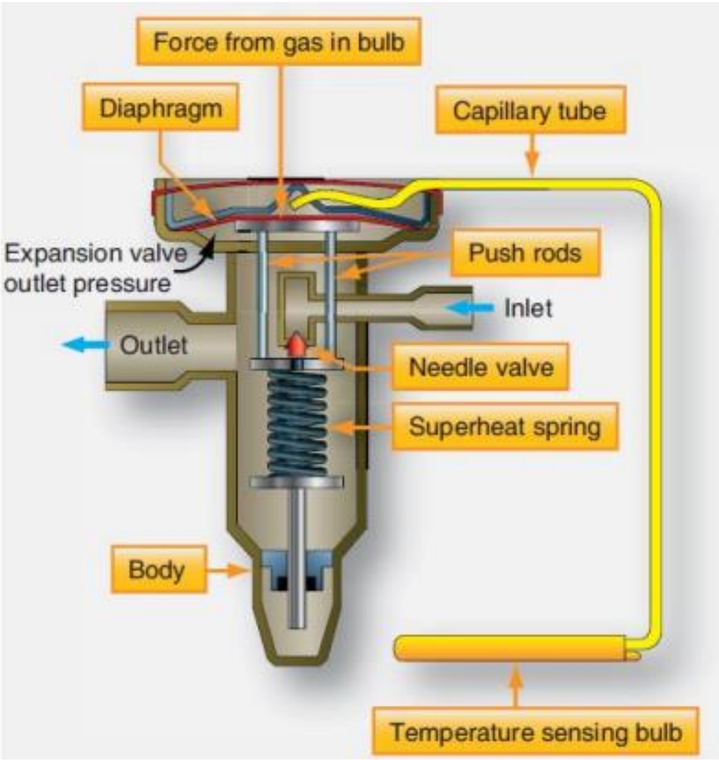


Figure 2.10 Expansion valve compartments [20]

When the temperature of the refrigerant rises, the pressure increases and the diaphragm overcomes the force of the spring, allowing a greater amount of refrigerant to pass through the evaporator unit. If the liquid exceeds the required amount, the temperature drops, which leads to pressure from the spring on the diaphragm, preventing further flow of cold liquid. In the final stage, the cold air generated in the evaporator is conveyed to the desired area with the help of a fan. At the same time, the pressure of the refrigerant decreases and the refrigerant gas evaporates and returns to the compressor, repeating this cycle as long as the system is in operation.

2.2.5 Refrigerant Gas

It is known that the properties of refrigerants can vary depending on the application and operating conditions. The selection of the refrigerant should be based on the application requirements and the purpose of the system. In the case of the FE-PCA unit, R410a refrigerant has been chosen. R410a is a type of refrigerant gas that belongs to the class of refrigerants and is widely used in the HVAC industry, particularly for air conditioning purposes. It is commonly used for both heating and cooling applications and is among the most commonly used refrigerants in daily life.

R410a is a refrigerant that belongs to the class of hydrofluorocarbons (HFCs), which are pressurized, liquefied or highly volatile fluorinated hydrocarbon compounds. It consists of two components: difluoromethane (CH2F2) and pentafluoroethane (CF3CHF2). Compared to other refrigerant gases, R410a offers higher efficiency and energy savings. The physical properties of R410 gas are shown in Table 2.1.

Table 2.1 R410A physical properties [21]

Properties	Values
Chemical Formula	CH2F2/CHF2CF3 (50/50% by weight)
Molecular Weight	<72.58
Boiling Point at One Atmosphere	–51.58 °C (–60.84 °F)
Critical Temperature	72.13 °C (161.83 °F) 345.28 K (621.50°R)
Critical Pressure	4926.1 kPa (abs) (714.50 psia)
Critical Density	488.90 kg/m3 (30.52 lb/ft3)
Critical Volume	0.00205 m3/kg (0.0328 ft3/lb)

The density of R410A refrigerant is approximately 3.5-4 times higher than that of air. Particularly when compared to air, R410A gas exhibits high density and thermal conductivity. This naturally leads to better heat conduction through the gas and this conduction can be further enhanced by increasing the ambient pressure and utilizing fans. In Figure 2.11, illustrates the pressure-temperature curve of R410A gas. As shown in the figure, the change in pressure is linear with respect to working temperatures. For a gas to be considered ideal, its pressure and temperature should vary proportionally. In cooling systems, these pressure-temperature measurements are crucial for evaluating cooling performance. In the case of R410A refrigerant, which is known as a blend gas, the pressure-temperature relationship may have a slight deviation of a few degrees [22].

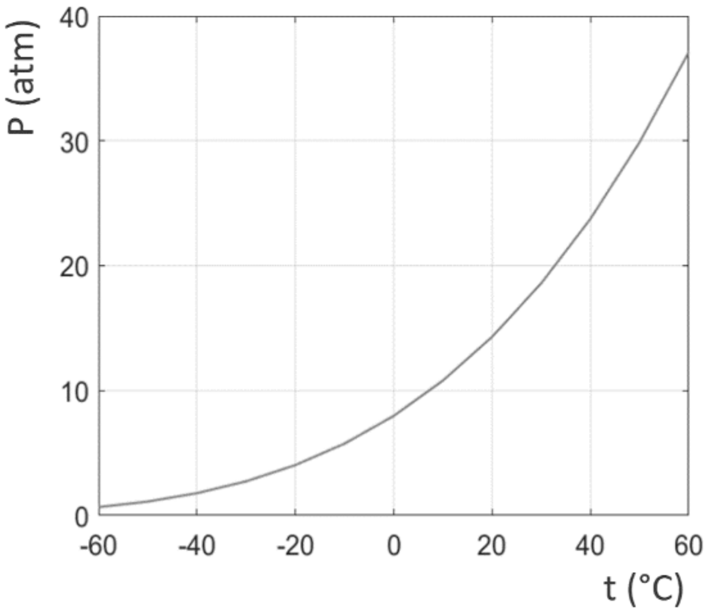


Figure 2.11 The pressure-temperature curve of R410A gas

2.2.6 Axial ve Centrifugal Fans

Fans are structures that create a pressure difference to facilitate the flow of air and other gases. Selecting the right fan is crucial for HVAC systems in terms of efficiency and performance. Fans can be either radial or axial (see Figure 2.12). Axial fans are preferred for high-volume flows and low-pressure increase. One of the reasons why axial fans and radial fans differ from each other is that the movement of air generated by the pressure difference in axial fans is in the axial direction, while in radial fans, it is directed by centrifugal force.

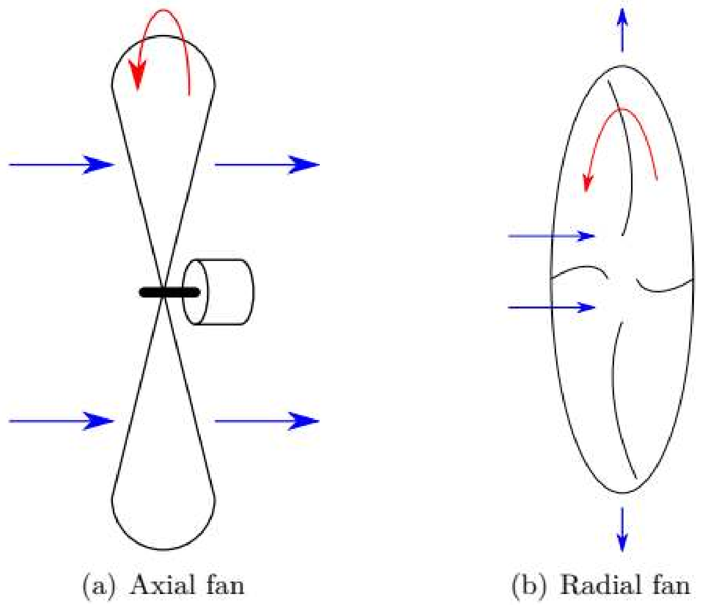


Figure 2.12 Rate flow direction indication of axial and radial fans

- Axial Fans

Axial fans are fans that move air in a straight line parallel to the axis of the shaft without changing its direction. They provide fast air transfer. In axial fans, the direction of the fluid flow is axial, meaning it is parallel to the rotation axis or the fan shaft. In many applications of axial flow fans, air is used as a fluid operating at medium pressure and low velocity. Since the working range of air is mostly incompressible, the change in air density is very small compared to the change in air pressure and can be neglected [23]. This is why the power transmission mechanisms do not cause efficiency reduction in this fan system, as the fan blades are directly connected to the motor shaft. Structure and Air Flow Mechanism of Axial Fans is shown Figure 2.13.

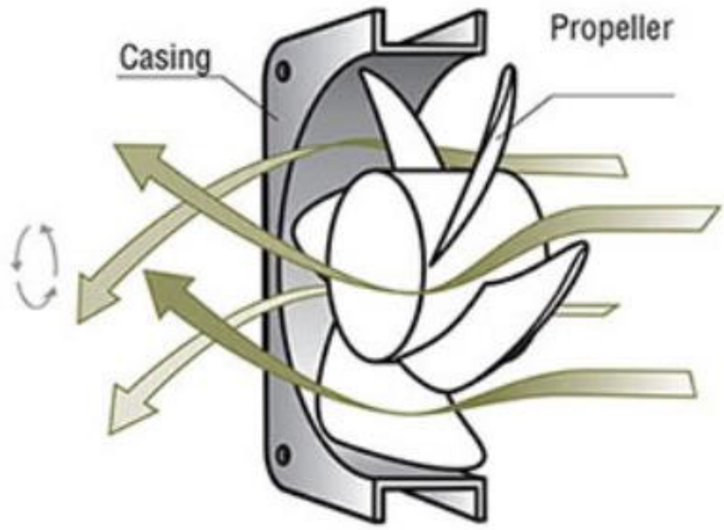


Figure 2.13 Structure and air flow mechanism of axial fans [24]

The use of axial fans in cooling systems is very common because they allow for large-volume flows and low pressure increase. Their affordability, compactness and light weight make them the optimal choice for cooling systems, providing a design advantage. Flow and pressure adjustments are made by adjusting the angle of the blades used in axial flow fans. Fan blades are typically made of bakelite and aluminum. To cater to a wide range of applications, there are different types of axial flow fans categorized based on their pressure increase and flow capacities.

- Centrifugal Fans

Centrifugal fans or blowers are components used for air movement in HVAC systems. They offer high energy efficiency and versatility. During operation, the fan or impeller is rotated by an electric motor. The rotation of the fan blades imparts kinetic energy to the air, resulting in airflow and the creation of pressure difference. Air is drawn in from one or both sides of the centrifugal fan impeller. The movement of the generated air is not axial but rather in the direction of centrifugal centrifugal force. In Figure 2.14 provides a schematic representation of the main components of a radial fan.

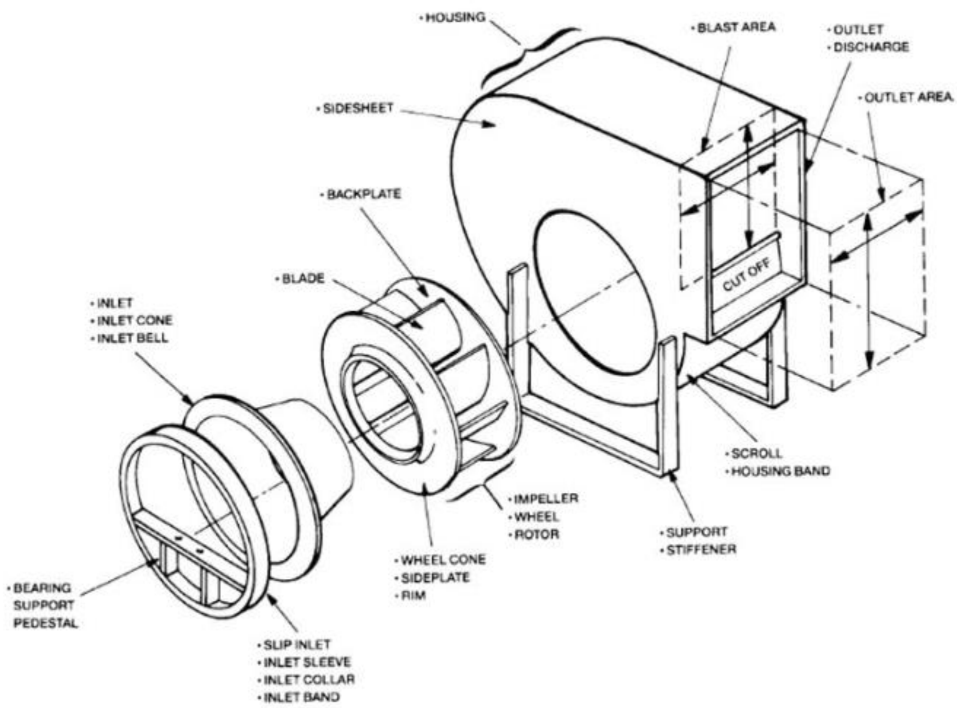


Figure 2.14 Shematic of main parts of a centrifugal fan

The centrifugal fan impeller is enclosed by a protective cover called a scroll or fan housing. Additionally, thanks to their 3D blade shapes, they provide low rotational noise, making them an excellent choice for cooling systems.

2.2.7 Liquid Receiver

A Liquid receiver is a storage tank used for storing liquid coolant and is located after the condenser in a cooling system. The Liquid receiver is an essential component of the entire system as it facilitates the transfer of liquid coolant to the expansion device. Its use is recommended during the operation of the expansion valve. If maintenance work is required on the cooling circuit in a low-pressure line, the liquid receiver can also be used to store the coolant. Liquid receiver (see Figure 2.15) can be used in various industrial applications and can be specifically designed for the storage of different liquid substances. These receiver are typically made from suitable materials to preserve the quantity and quality of the liquid and ensure the safe and efficient management of the liquid substance.

Figure 2.15 Liquid receiver

2.2.8 Filter Drier

Filter driers (see Figure 2.16) are devices used in HVAC systems that combine a filter and a dryer. The dryer is designed to capture debris, particles and contaminants that may detach from the refrigeration system.

Figure 2.16 Types of air conditioner filter driers

The filtration of these particles and prevention of harmful substances is of critical importance. Dryers are generally installed between the condenser and the expansion valve. When moisture comes into contact with the oil in the system, it can lead to the formation of acid and sludge. Therefore, the dryer, with its silica gel content, has the ability to collect acid and moisture in the cooling system. If a cooling system does not have a dryer, the compressor may eventually malfunction or freezing can occur in the capillary tubes after the expansion valve. Freezing in the system leads to reduced or complete blockage of gas circulation, so it is necessary to remove moisture from the system; otherwise, the frozen moisture inside the tube can restrict the flow of refrigerant. The dryer serves as a drying filter in this regard. A cutaway of a liquid line filter drier is shown Figure 2.17.

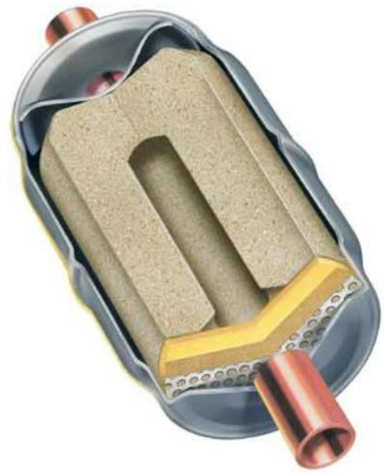


Figure 2.17 A cutaway of a liquid line filter drier [25]

Only dry refrigerant gas and refrigeration oil should be used in the refrigeration system. When making system connections, the air entering the system creates excessive humidity within the system. Although a vacuum is performed to remove the air before charging the system with gas, a certain amount of moisture may remain in the system, leading to icing in the refrigeration system. Particularly in systems with low refrigerant levels, the main cause of icing is refrigerant gas leakage, which allows air to enter the system and leads to water accumulation. In this context, the dryer plays an important role in protecting the system. By installing a sight glass near the point where the dryer is connected to the system, liquid accumulation can be observed. If there is liquid in the system, the color of the green stripe on the sight glass turns yellow.

2.2.9 Sight Glass

Sight glass is an auxiliary system component that allows monitoring of the liquid level and humidity condition of the refrigerant in cooling systems. Its main function is to assist in determining whether the filter is performing its function properly. It features an indicator that changes color based on the moisture levels in the liquid refrigerant. The indicator displays different color tones, allowing for observation of the moisture condition within the refrigerant. These colors indicate that the filter-dryer in the system is not functioning properly. The solution to this problem involves checking the filter-dryer in the refrigeration system. The sight glass serves as an auxiliary element applied to the system after the condenser outlet and the dryer filter (see Figure 2.18).

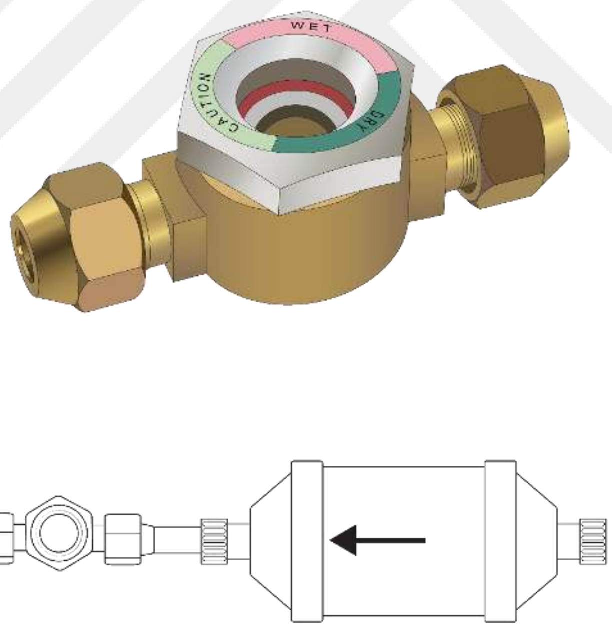


Figure 2.18 Sight Glass

The outer body of the sight glass is typically made of pressure cast, pressed or solid rod material. It can also be made from brass or steel. The sight glass with its pressure resistance can always provide a clear view. Special rubber o-ring application is used to ensure sealing in both directions.

To check for any leaks in the refrigerant system, a safe amount of liquid or vapor is charged into the system. Then, heat load is applied to the system and it is allowed to stabilize until the suction and discharge pressures of the compressor become steady. Afterwards, the sight glass is observed for the presence of bubbles. If bubbles are continuously seen, it indicates that the refrigerant quantity in the system is low. In this case, vapor phase refrigerant is added to the system while the compressor is running until the bubbles disappear. The absence of bubbles after a certain waiting period indicates that the appropriate amount of refrigerant charge has been achieved.

2.2.10 Rezistans (Serpentine)

Resistance is the general term for the resistance wires that convert electrical energy into heat energy. Resistance refers to the power of a material to resist the flow of electric current when a voltage is applied across its two terminals. Resistance is denoted by the letters "R" or "r". Resistance exhibit resistance to very high temperatures. Resistance wires are made of chromium (Cr), aluminum (Al), nickel (Ni) and iron (Fe) alloys. Chromium (Cr) increases the resistance of the resistance against the heat produced by itself. Aluminum (Al) prevents the oxidation of the wire in the air after it reaches a stable state. Nickel provides resistance against chemical factors. Resistance have different operating temperatures depending on the alloys of nickel, chromium, aluminum and iron.

With advancing technology, resistance have started to be used in various fields, primarily in heating technology and they hold a significant place. Depending on the intended application and devices, resistance are produced in different models and types, each designed separately. In the designed system, for the purpose of energy efficiency and ease of installation, a serpentine resistance has been chosen. Serpentine resistances, (see Figure 2.19) commonly known as finned heaters, generally facilitate heat transfer through air circulation.

Figure 2.19 Serpentine resistance

A serpentine resistances is a heating equipment that utilizes bent or curved tubes to enhance heat flow. Serpentine resistances typically have pipe diameters ranging from 6.5mm to 20mm, depending on the requirements. The coil diameters can vary from 20mm to 50mm in direct proportion to the pipe diameters. Serpentine resistances are produced with supply voltages ranging from 24V to 500V DC. To facilitate the installation process, couplings can be added to the heads of the heaters

2.2.11 Filter

The operating system of air conditioners is based on the principle of drawing in high-volume air and circulating hot or cold air in the environment. The air contains a significant amount of pollutants. In light of this, it is crucial to use certain equipment to separate the pollutants in the air before they are used in the air conditioning system. During this process, filters play a vital role in cleaning the air and enabling the circulation of clean air. Bacteria and various microorganisms can cause product contamination and loss. When it is desired and necessary to separate the highest number of microorganisms from the air, high-efficiency particle filters are used. In Figure 2.20, shows an example of a filter.

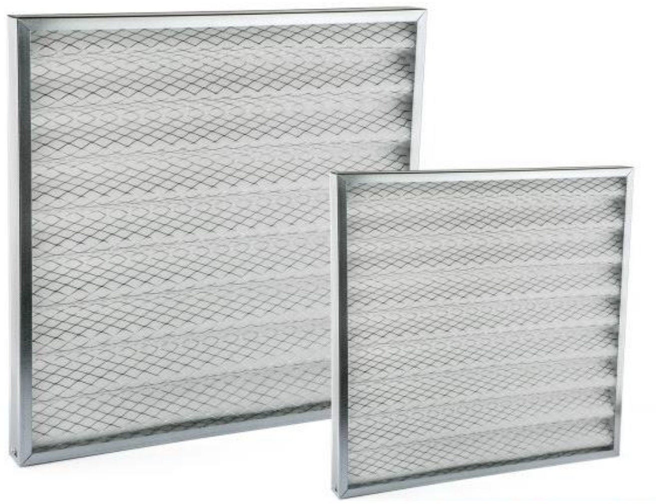


Figure 2.20 Air filter

Even if the other units of the system are clean, it is essential to ensure that the necessary standards for filter cleanliness are met. Filter cleanliness is important for energy efficiency and the longevity of the system. Neglecting filter cleanliness can result in the accumulation of particles, leading to frost formation on the evaporator and a decrease in cooling efficiency. The device consumes more electricity and its lifespan is reduced. Therefore, filter maintenance and cleaning should be performed at regular intervals.

2.2.12 Thermostat

Thermostats are devices that control the temperature of a desired space by turning on and off fan units and electric heaters in heating, cooling and ventilation applications. They enable HVAC devices to operate according to desired settings. They also allow for the stabilization of the desired temperature in a specific area. If the set temperature value on the device exceeds a critical value, the thermostat cuts off the energy supply. When used for cooling purposes, the thermostat's function is to disable the compressor once the set temperature value is reached. This ensures continuous protection of the system. Thermostats are available in different categories based on their operating principles, such as mechanical and digital thermostats. Both mechanical and digital thermostats are connected to the system using cables. When thermostats are used correctly and optimized, they provide energy savings. Considering energy savings, operating principles, connection and installation options, the use of a mechanical thermostat is deemed suitable in the system designed.

2.2.13 Copper pipes

In refrigerant systems, the connection between many components is made using copper pipes (see Figure 2.21). The length and diameter of the copper pipes that connect the system elements are important to ensure the proper flow of refrigerant at the appropriate pressure to the components. It is necessary to perform the installation with suitable piping distances and pipe diameters for the efficient operation of the system. The key characteristics sought in the pipes include high corrosion resistance, compatibility with shaping and joining techniques, surface quality and thermal conductivity. Copper and its alloys are materials that meet all these mentioned characteristics. Therefore, copper has become the fundamental material for the heating, cooling and air conditioning industry. Copper pipes are made of 99.9% pure copper with small amounts of alloying elements, in accordance with the standards published by ASTM. The economic aspect is also a significant factor in the selection of these pipes.

Figure 2.21 Copper pipes

With a properly designed refrigerant piping system, sufficient coolant flow is ensured to the evaporators by using refrigerant lines that limit pressure drop. Care is taken to avoid excessive oil trapping to ensure proper operation of the compressor and sufficient oil supply. It prevents the clogging of liquid refrigerant and is resistant to corrosion and prolonged exposure to high water pressure.

2.2.14 Joining Elements

In refrigerant flow systems, the distribution of refrigerant to all components is achieved through connection elements called refnet joints, using a single copper pipe line. Different types of joints separate the gas flowing through a single copper pipe into multiple branches to distribute it to all components. The header, on the other hand, divides the incoming gas from a single line into multiple branches to facilitate distribution.In Figure 2.22, depicts some of the joining elements used in system piping.

Figure 2.22 Piping joining elements

CHAPTER 3

SELECTION OF COOLING SYSTEM COMPONENTS

3.1 System Scheme and Specifications

To ensure the continuity of military operations, the specified values should be brought to the optimum temperature. The Mobile FE-PCA unit is designed for processes such as maintenance, repair and ground testing of unmanned aerial vehicles. Due to the excessive heat dissipation from the avionics of unmanned aerial vehicles, it is aimed to keep the avionics at an optimum temperature of 12 °C during operation to prevent damage and minimize system losses. The installed system is unique and tailored to the specific requirements of a particular unmanned aerial vehicle, distinguishing it from other PCA units.The general refrigerant scheme of the FE-PCA unit is shown in Figure 3.1 and the system specifications are presented in Table 3.1.

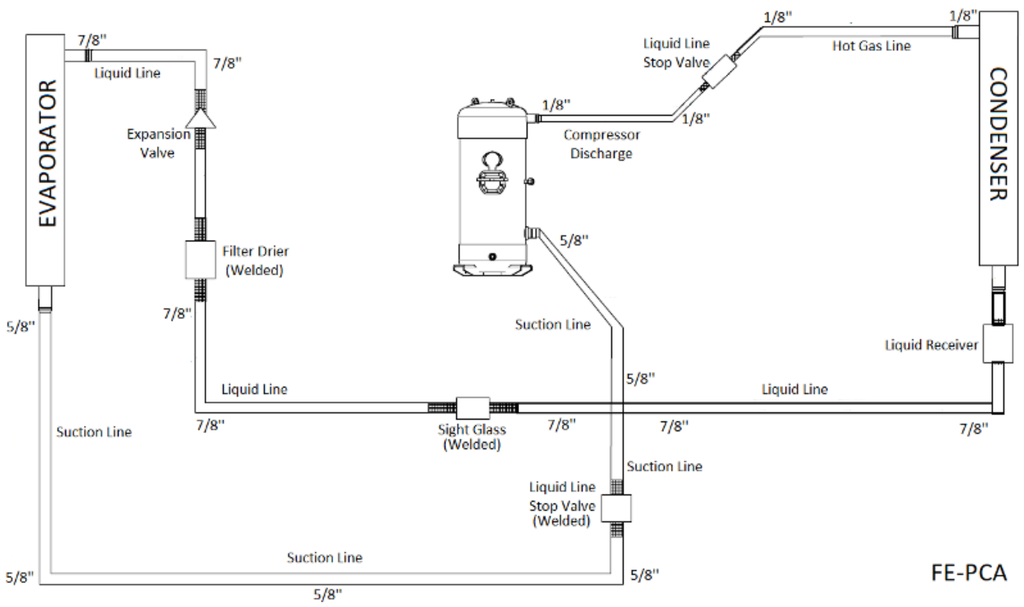


Figure 3.1 FE-PCA unit general refrigerant scheme

Table 3.1 System specifications of the FE-PCA unit

Specifications	Values
Heating Capacity	13,4 KW
Cooling Capacity	21.6 KW
Heating Principle	Resistance
Cooling Principle	Ideal Vapor Compression Refrigeration Cycle
Electrical Consumption (During Heating)	13.6 kW/h
Electrical Consumption (During Cooling)	5.9 kW/h
Voltage and frequency	380 V / 50 Hz.
Refrigerant Gas	R410A
Filtration	G4 Filter

3.2 Layout of System Units

The component and piping layout of the cooling fluid system in the FE-PCA unit is shown in Figure 3.2 and the system component list is presented as shown in Table 3.2.

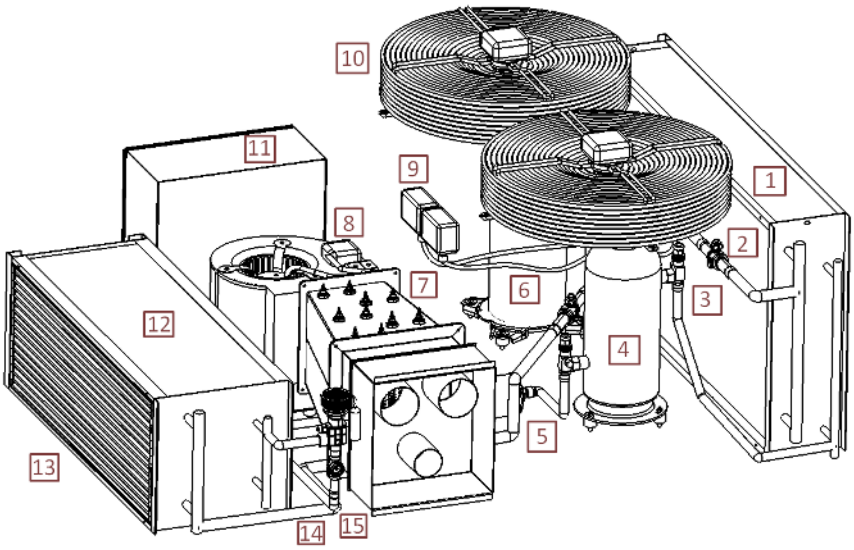


Figure 3.2 Components and system piping of the refrigerant flow system of the FE-PCA unit

Table 3.2 System components list of FE-PCA unit

#	System Components	Properties
1	Condenser	1100 mm x 559 mm x 180 mm
2	Hot Gas Bypass Valve	Danfoss, CPCE 12,034N0082
3	Rotolock Valve	Danfoss, 7968008
4	Liquid Receivers	GVN, V6A.33b.07.A2.A2.F4
5	Filter Drier	Danfoss, Hermetic filter drier, DML, Steel, 023Z0110
6	Compressor	Danfoss, VZH044CGANB
7	Resistance	10 x Serpentine
8	Centrifugal Fan	Nicotra, DDM 9/7 TIGHT E6G3405 1F 4P 1V
9	Pressure switch	Danfoss, KPI35, 060-121966
10	Axial Fans	SFX 4M 500 - A01
11	Electrical Panel	400 mm x 400 mm x 200 mm
12	Evaporator	900 mm x 318 mm x 320 mm
13	G4 / EU4 Filtre	846 x 292 x 48 mm
14	Sight glass	Hongsen SGN-7/8
15	Expansion Valve	Danfoss TGEL 10-6

3.3 Energy Consumption Data

For the energy consumption amount of the system, it was made using the Hvac Calculator program.When the ambient temperature is 45°C, cooling needs to be provided for the outlet temperature to reach 10°C, requiring approximately 30.17 KW of cooling capacity. Assuming a COP value of approximately 2.5; energy consumption will be 12.07 KW (see Figure 3.3).

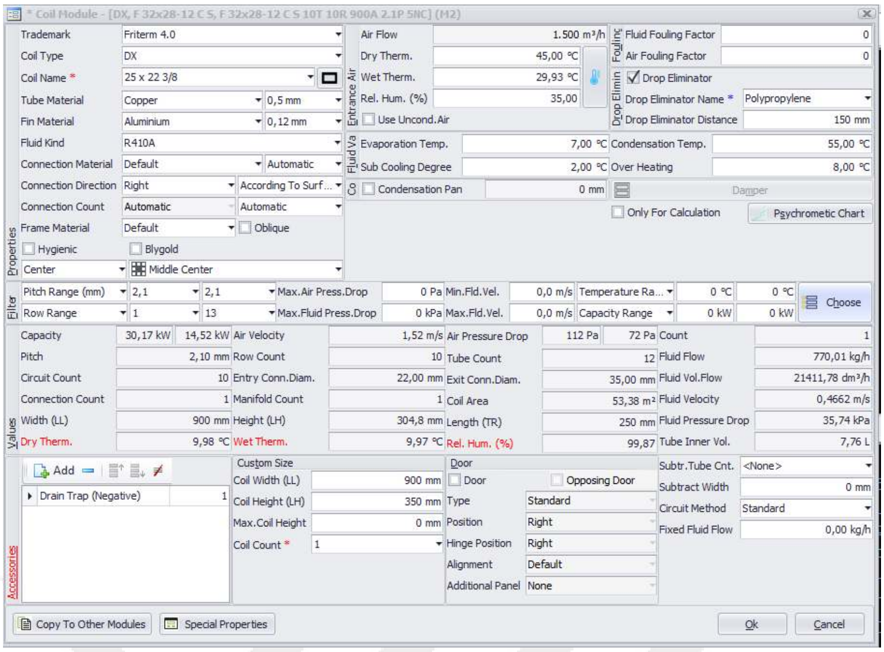


Figure 3.3 System data when ambient temperature is 45°C, output temperature is 10°C

When the ambient temperature is 40°C, cooling needs to be provided for the outlet temperature to reach 10°C, requiring approximately 25.6 KW of cooling capacity. Assuming a COP value of approximately 2.5; energy consumption will be 10.24 KW (see Figure 3.4).

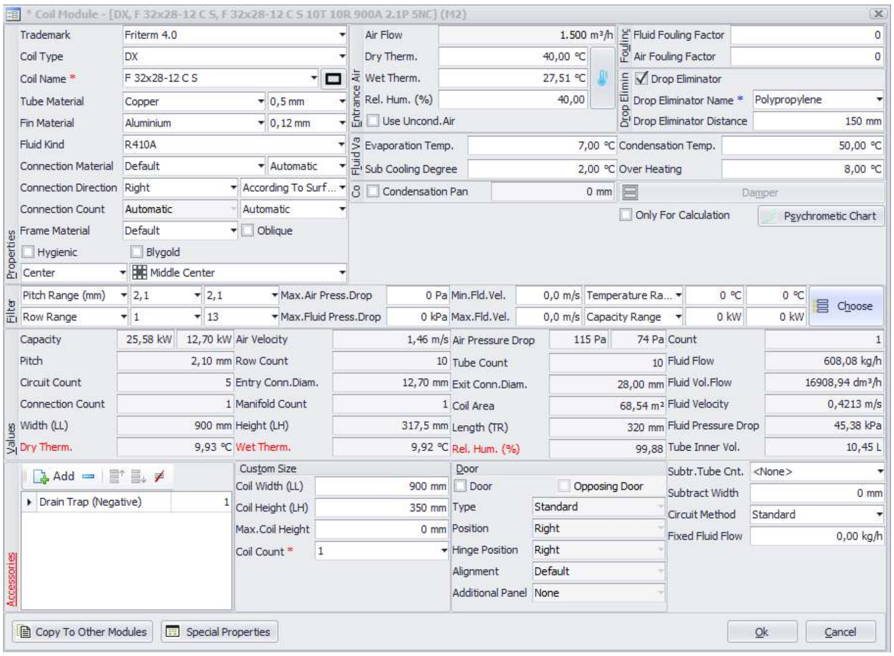


Figure 3.4 System data when ambient temperature is 40°C, output temperature is 10°C

When the ambient temperature is 34°C, cooling needs to be provided for the outlet temperature to reach 10°C, requiring approximately 21.6 KW of cooling capacity. Assuming a COP value of approximately 2.5, energy consumption will be 8.64 KW (see Figure 3.5).

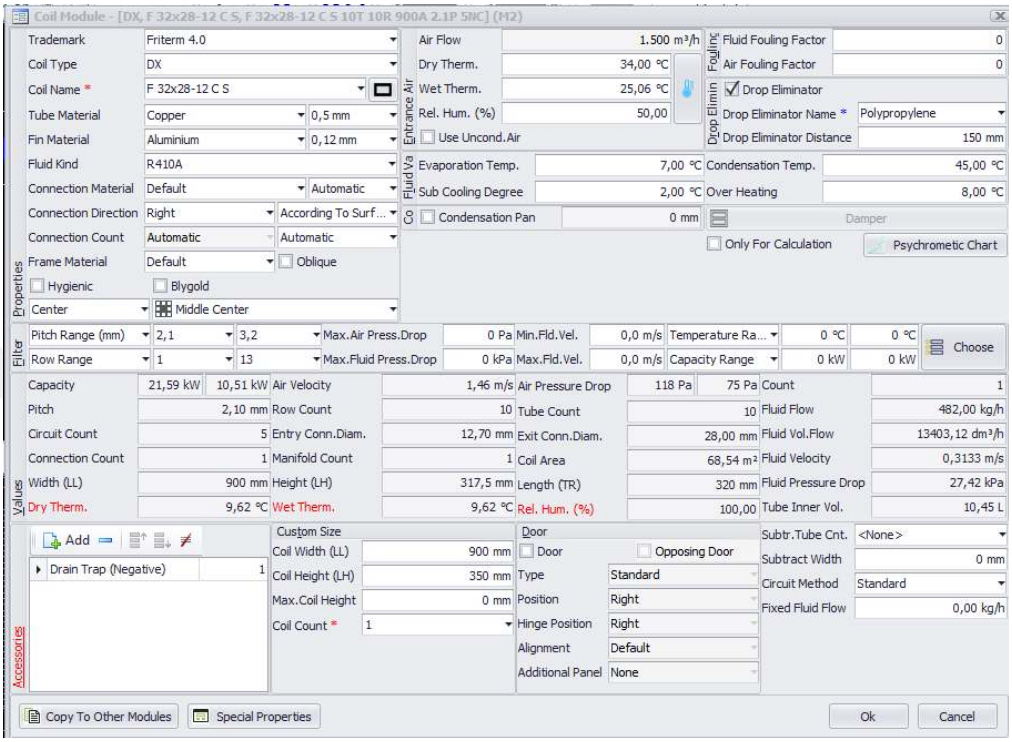


Figure 3.5 System data when ambient temperature is 34°C, output temperature is 10°C

When the ambient temperature is 30°C, cooling needs to be provided for the outlet temperature to reach 10°C, requiring approximately 17.23 KW of cooling capacity. Assuming a COP value of approximately 2.5, energy consumption will be 6.9 KW (see Figure 3.6).

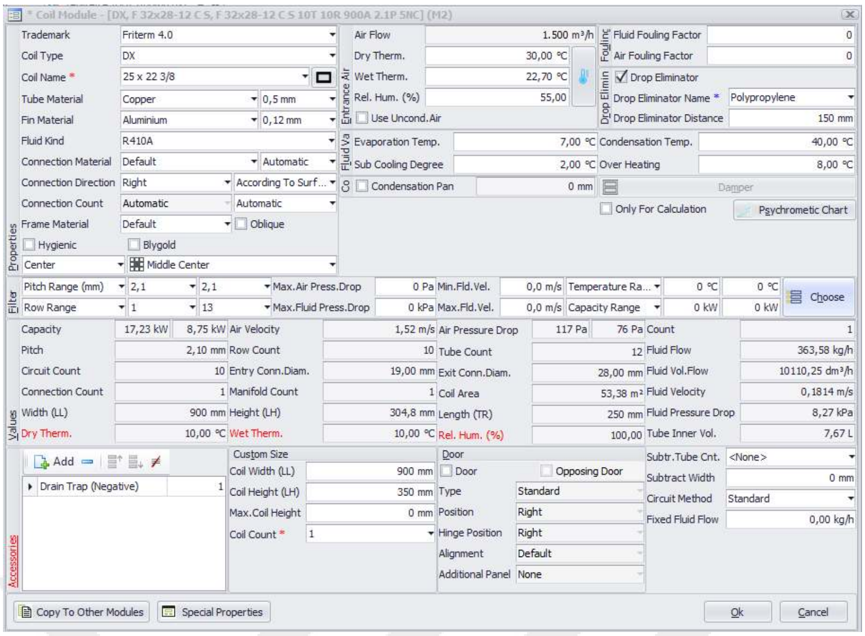


Figure 3.6 System data when ambient temperature is 30°C, output temperature is 10°C

When the ambient temperature is 25°C, cooling needs to be provided for the outlet temperature to reach 10°C, requiring approximately 12.12 KW of cooling capacity. Assuming a COP value of approximately 2.5, energy consumption will be 4.85 KW (see Figure 3.7).

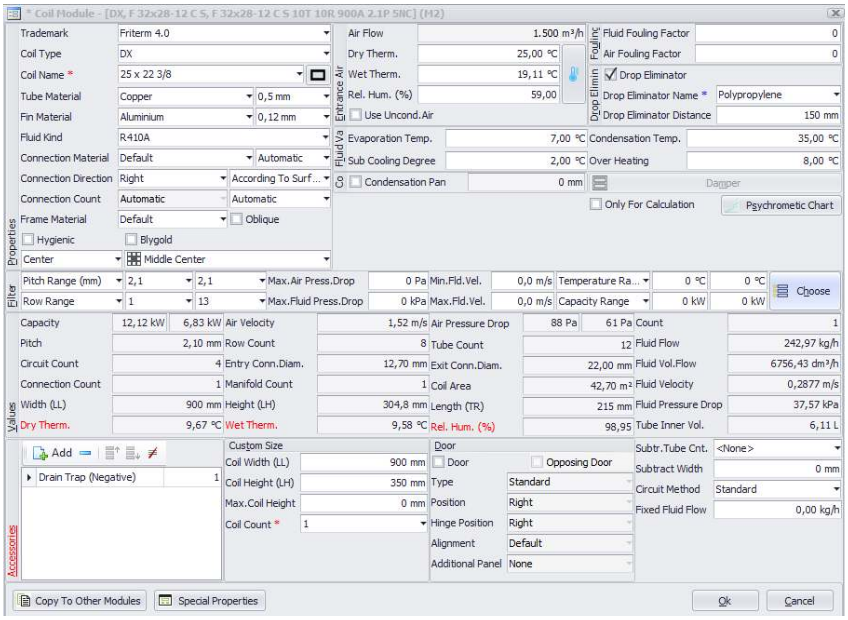


Figure 3.7 System data when ambient temperature is 25°C, output temperature is 10°C

The flow rate for system requirements is assumed to be 1500 m3/h and the cooling demand is assumed to be 22 kW. The calculations are based on these values.

It is deemed suitable to use an inverter-controlled Danfoss brand Scroll compressor for the cooling demand of 22 kW. The use of an inverter will increase energy efficiency in the device and prevent the compressor from operating in continuous on/off scenarios.

Maximum operating conditions of the device are assumed to be as follows:

Air conditioning system;

- -32 to +50 degrees Celsius temperature range,

Operating conditions of the unit in ambient environment are assumed to be as follows: Air conditioning system:

- -32 to +34 degrees Celsius temperature range,
- It will provide 22 kW of cooling at 50% relative humidity,
- It is designed to have a supply air temperature of 10°C.

3.4 Compressor Selection

According to the specified conditions, the condensing temperature, which should be approximately 10°C higher than the operating condition, is determined as 45°C. The evaporating temperature, which should be 2-3°C lower than the supply air temperature, is determined as 7°C.

Selection was made using Danfoss "Cool Selector 2" program (see Figure 3.8).

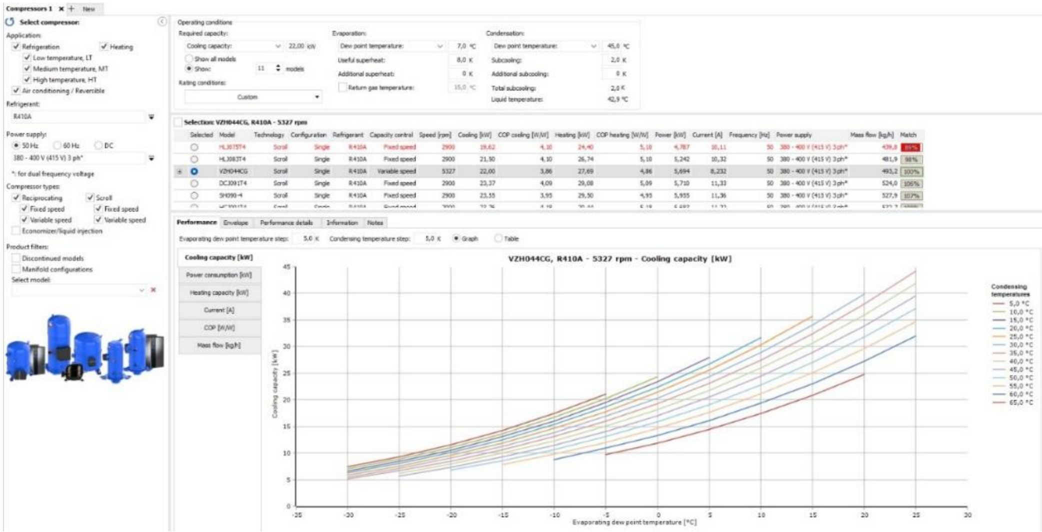


Figure 3.8 Compressor selection outputs

Compressor selected for these conditions is the "Danfoss VZH044CGANB".

Refrigerants: R410A

Segment usage: Air conditioning

Compressor power supply [V/Ph/Hz]: 380-480/3/50-60

3.5 Condenser Selection

Condenser selection was made using the HVAC Calculator program. The inputs for the HVAC Calculator program are as follows;

- Coil Type: Condensing
- Tube Material: Copper
- Fin Material: Aluminum
- Refrigerant Type: R410A
- Air Flow Rate: 14000 m3/h (7000 m3/h x 2 fan)
- Dry Bulb Temperature: 35°C
- Relative Humidity: 50%
- Evaporating Temperature: 7°C
- Condensing Temperature: 45°C

- Subcooling: 2°C
- Superheat: 8°C

The selected condenser based on these inputs is as follows (see figure 3.9).

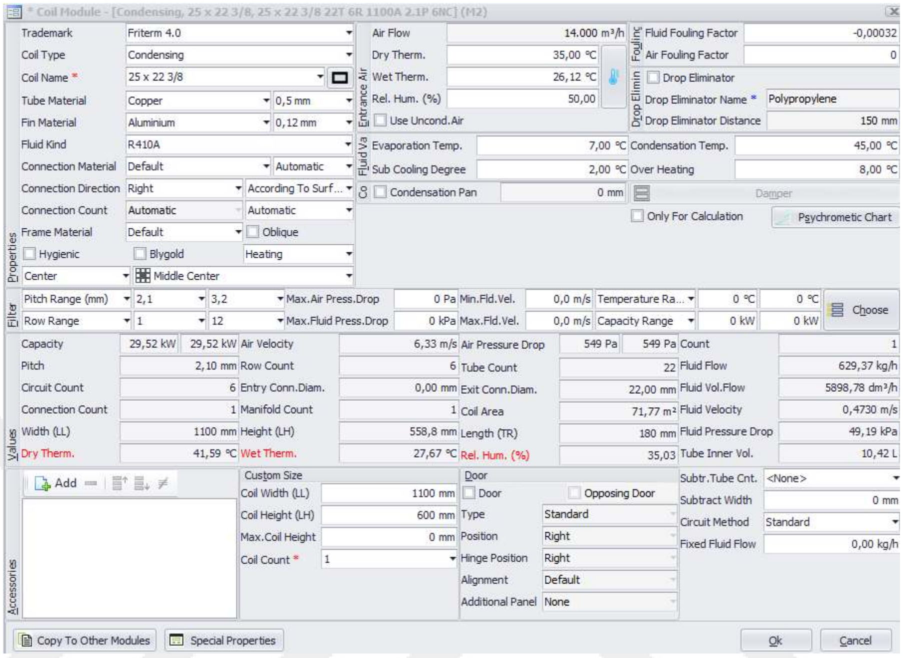


Figure 3.9 Selected condenser inputs

Outputs of the selected condenser are as follows (see Figure 3.10).

COIL (Condensing) (M2)

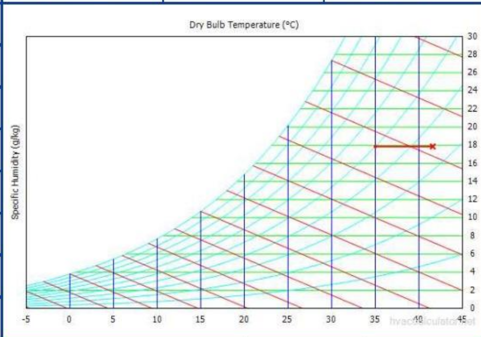
Air Flow	Capacity	Required Capacity	Face Velocity	Pitch	Quantity	Section Weight
14.000 m³/h	29,52 kW		6,33 m/s	2,1	1	291,9 kg

Coil Code	Tube Material	Fin Material	Function
25 x 22 3/8 22T 6R 1100A 2.1P 6NC	Copper	Aluminium	Heating

Droplet Elimin. / Press. Drop	Condensation Pan / Hmin U-Trap	Tube Thickness	Fin Thickness	Mixing Ratio
		0,5 mm	0,12 mm	%

Fluid Kind	Evaporation/Condensation/SCD/OH	Size (W x H x L) mm	Conn. Material	Frame Material
R410A	7/45/2/8 °C	1.100 x 559 x 180	Copper	Galvanized Steel

Air Inlet Drybulb Temperature 35 °C	**Air Outlet Drybulb Temperature** 41,59 °C
Air Inlet Wetbulb Temperature 26,12 °C	**Air Outlet Wetbulb Temperature** 27,67 °C
Air Inlet Relative Humidity 50,00 %	**Air Outlet Relative Humidity** 35,03 %
Air Inlet - Outlet Enthalpy 81 - 87,85 kJ/kg	**Fluid Flow / Vol. Flow** 629 kg/h / 5.899 dm³/h
Air Press.Drop 549 Pa	**Fluid Press.Drop / Fluid Velocity** 49,19 kPa / 0,47 m/s
Coil Surface Area 71,77 m²	**Tube Inner Volume** 10,42 L
Manifold / Conn.QTY 1 / 1	**Conn.Direction** Right
Connection Sizes 0 / 22 mm (/ 7/8" DN20)	



Bypass Damper	Air Condensation	Hygienic	Blygold
	0,0000 l/h	☐	☐

Figure 3.10 Selected condenser outputs

- Total Capacity: 29.52 kW
- Coil Air Velocity: 6.33 m/s
- Coil Air Outlet Dry Bulb Temperature: 41.59°C
- Coil Air Outlet Wet Bulb Temperature: 27.67°C
- Coil Air Outlet Relative Humidity: 35.03%
- Air Pressure Drop: 49 Pa
- Coil Dimensions (W x H x D): 1100 mm x 559 mm x 180 mm

3.6 Condenser Fan Selection

Condenser fan selection "BVN Fan Selector" program was used. Fan Selector program inputs (see Figure 3.11):

- Fan Type: Axial Fans
- Design Point: Static Pressure
- Airflow Rate: 7000 m3/h (2 units will be used, total 14000 m3/h)
- Tolerance: 10%
- Air Density: 1.204 kg/m3

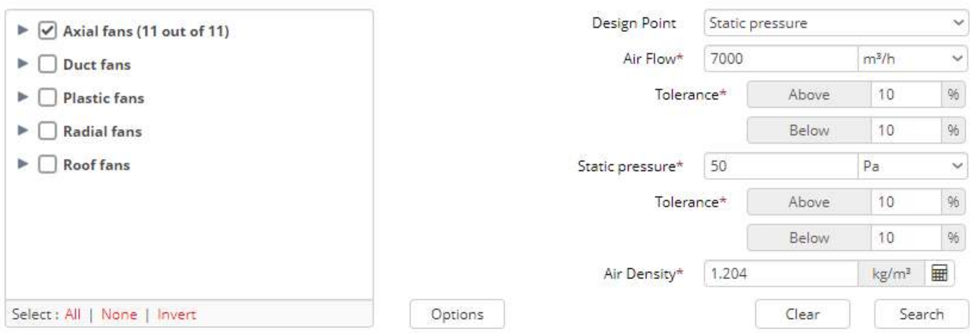


Figure 3.11 Condenser fan inputs

Based on these inputs, a selection has been made for 2 units of "SFX 4M 500-A01" fan. The pressure-flow curve of the selected fan is as follows (see Figure 3.12).

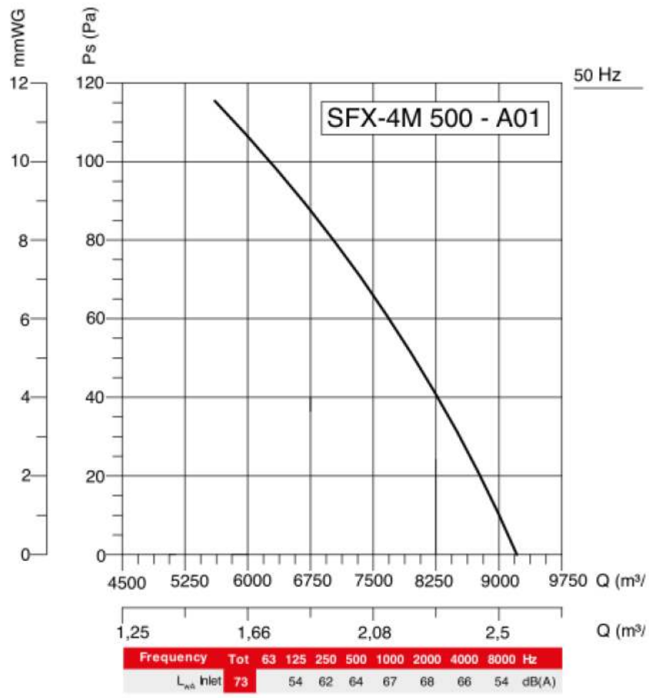


Figure 3.12 Pressure-flow curve of SFX 4M 500-A01

3.7 Evaporator Selection

Evaporator selection has been made using the HVAC Calculator program. Here are the inputs for the HVAC Calculator program;

- Coil Type: DX
- Pipe Material: Copper
- Fin Material: Aluminum
- Refrigerant Type: R410A
- Air Flow Rate: 1500 m3/h
- Dry Bulb Temperature: 34°C
- Relative Humidity: 50%
- Evaporation Temperature: 7°C
- Condensation Temperature: 45°C
- Subcooling: 2°C
- Superheat: 8°C

The selected evaporator condenser based on these inputs is as follows (see figure 3.13).

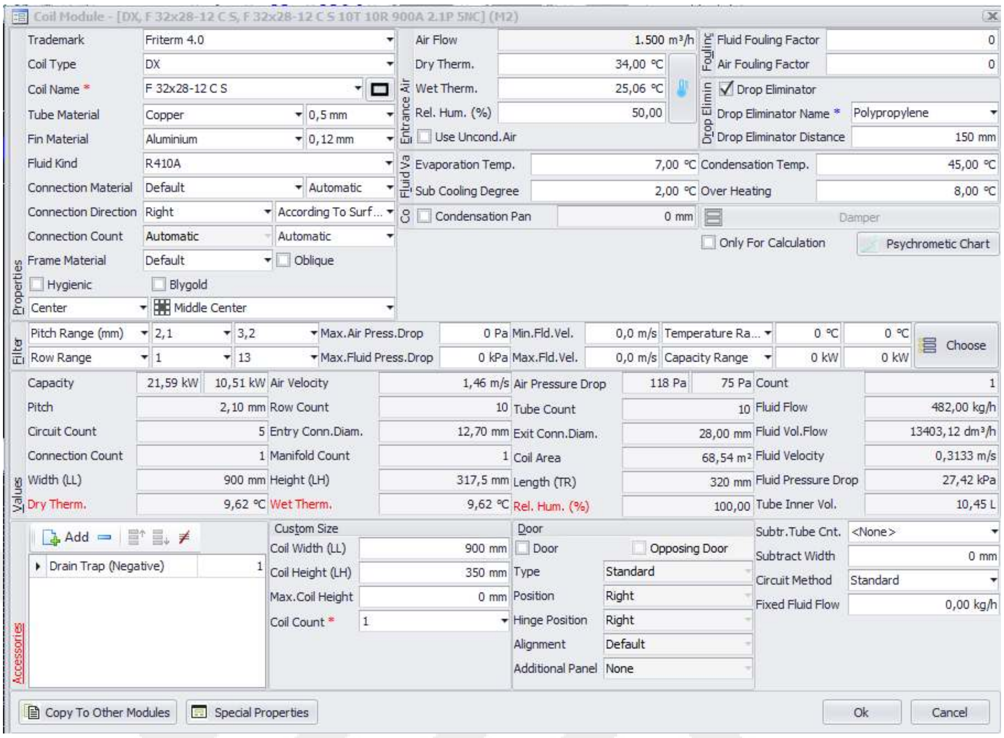
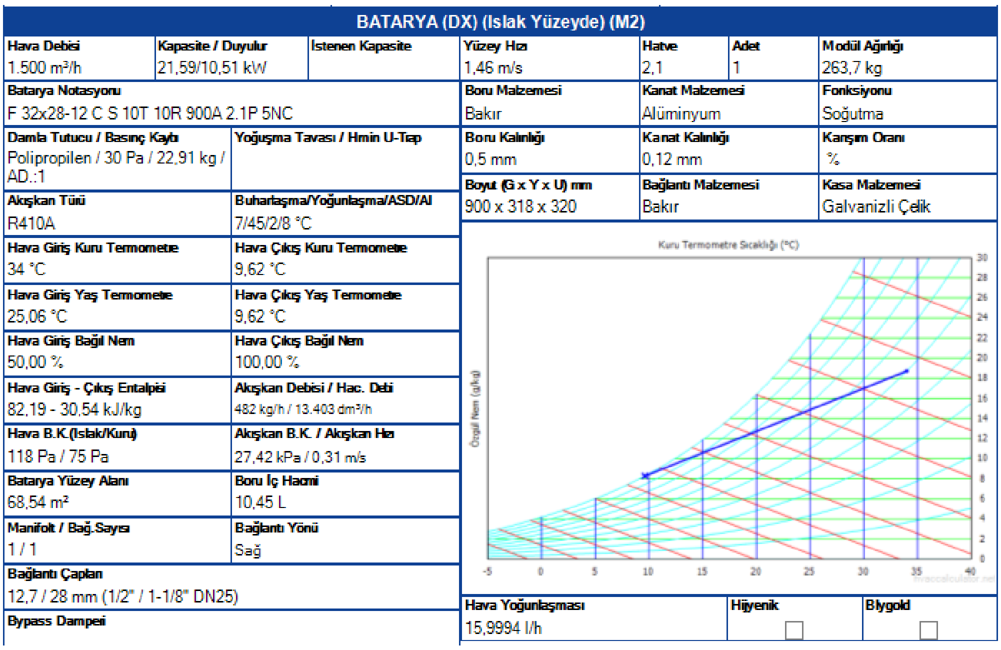


Figure 3.13 Selected evaporator inputs

Outputs of the selected evaporator are as follows (see Figure 3.14).



BATARYA (DX) (Islak Yüzeyde) (M2)						
Hava Debisi 1.500 m³/h	**Kapasite / Duyulur** 21,59/10,51 kW	**İstenen Kapasite**	**Yüzey Hızı** 1,46 m/s	**Hatve** 2,1	**Adet** 1	**Modül Ağırlığı** 263,7 kg
Batarya Notasyonu F 32x28-12 C S 10T 10R 900A 2.1P 5NC			**Boru Malzemesi** Bakır	**Kanat Malzemesi** Alüminyum		**Fonksiyonu** Soğutma
Damla Tutucu / Basınç Kaybı Polipropilen / 30 Pa / 22,91 kg / AD.:1	**Yoğuşma Tavası / Hmin U-Tep**		**Boru Kalınlığı** 0,5 mm	**Kanat Kalınlığı** 0,12 mm		**Karışım Oranı** %
Akışkan Türü R410A	**Buharlaşma/Yoğunlaşma/ASD/AI** 7/45/2/8 °C		**Boyut (G x Y x U) mm** 900 x 318 x 320	**Bağlantı Malzemesi** Bakır		**Kasa Malzemesi** Galvanizli Çelik
Hava Giriş Kuru Termometre 34 °C	**Hava Çıkış Kuru Termometre** 9,62 °C					
Hava Giriş Yaş Termometre 25,06 °C	**Hava Çıkış Yaş Termometre** 9,62 °C					
Hava Giriş Bağıl Nem 50,00 %	**Hava Çıkış Bağıl Nem** 100,00 %					
Hava Giriş - Çıkış Entalpisi 82,19 - 30,54 kJ/kg	**Akışkan Debisi / Hac. Debi** 482 kg/h / 13.403 dm³/h					
Hava B.K.(Islak/Kuru) 118 Pa / 75 Pa	**Akışkan B.K. / Akışkan Hızı** 27,42 kPa / 0,31 m/s					
Batarya Yüzey Alanı 68,54 m²	**Boru İç Hacmi** 10,45 L					
Manifold / Bağ.Sayısı 1 / 1	**Bağlantı Yönü** Sağ					
Bağlantı Çapları 12,7 / 28 mm (1/2" / 1-1/8" DN25)			**Hava Yoğunlaşması** 15,9994 l/h		**Hijyenik**	**Blygold**
Bypass Damperi						

Figure 3.14 Selected evaporator outputs

- Total Capacity: 21.59 kW
- Sensible Capacity: 10.51 kW
- Coil Air Velocity: 1.46 m/s
- Coil Air Outlet Dry Bulb Temperature: 9.62°C
- Coil Air Outlet Wet Bulb Temperature: 9.62°C
- Coil Air Outlet Relative Humidity: 100%
- Air Pressure Drop: 118 Pa
- Coil Dimensions (W x H x D): 900 mm x 318 mm x 320 mm

3.8 Evaporator Fan Selection

Nicotra brand will be used for the evaporator fan. When selecting the fan, it is necessary to account for the pressure drop across the evaporator and the pressure drop recovery of the unmanned combat aerial vehicle (UCAV).

Pressure drop on the air side of the evaporator is assumed to be 118 Pa and the loss of pressure drop on the UCAV is assumed to be 200 Pa.

Total loss of pressure: 318 Pa.

According to these specifications, the Nicotra fan selected to provide a flow rate of 1500 m3/h with a loss of pressure 318 Pa is the "DDM 9/7 TIGHT E6G3405 1F 4P 1V SCT (50 Hz)". The technical data of the evaporator fan is shown in Figure 3.15 and the fan dimensions are illustrated in Figure 3.16.

NICOTRA|Gebhardt — Direct driven centrifugal fans / DDM / Technical Data

DDM 9/7 TIGHT E6G3405 1F 4P 1V +SCT

Technical Data

DDM 9/7 TIGHT E6G3405	Speed control	Curves	Nominal motor power W	Poles –	Phases	Connection	Mains frequency Hz	Max. power consumption W	Max. current consumption A	Speed 1/min
1F 4P 1V +SCT	(2)	[J3/J4]	420	4	1~		50/60	821	3.6	1320

Technical Data

DDM 9/7 TIGHT E6G3405	Operating Capacitor µF	Nominal capacitor voltage V	Motor protection class	Motor thermal class	Thermal protection	Media Temperature max. °C	Fan weight kg	Density of media kg/m³	Installation type (ISO 5801)	Article number
1F 4P 1V +SCT	16	450	IP55	F	EXT	40	16	1.2	B	6M02WY

(1) = Speed controllable via Transformer
(2) = Speed controllable via TRIAC or Transformer
(3) = Speed controllable via Inverter
* = No speed control available
[HI] High speed, [ME] Medium speed, [LO] Low speed

Attention! We suggest to do not use the fan in the grey marked area! The noise ratings given in the performance curves are sound power level L_{WA7}, see „Technical Description".

Curves

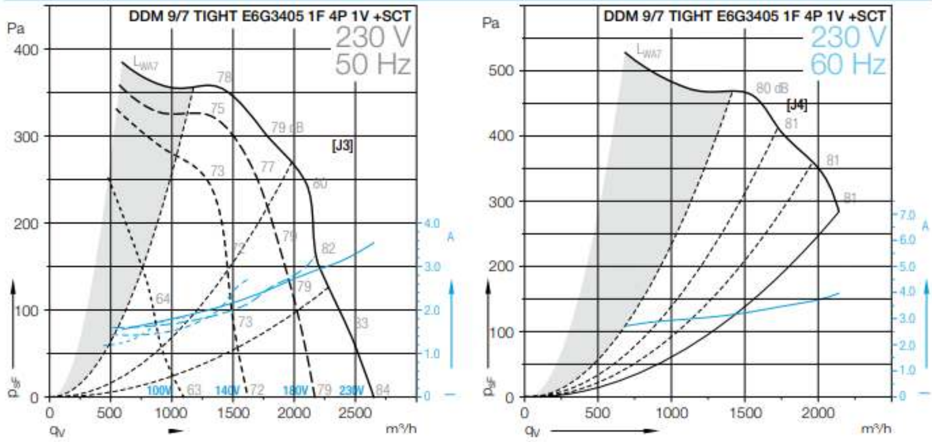


Figure 3.15 Technical data of evaporator fan DDM 9/7

Dimensions in mm, Subject to change.
DDM 9/7 TIGHT E6G3405 1F 4P 1V +SCT

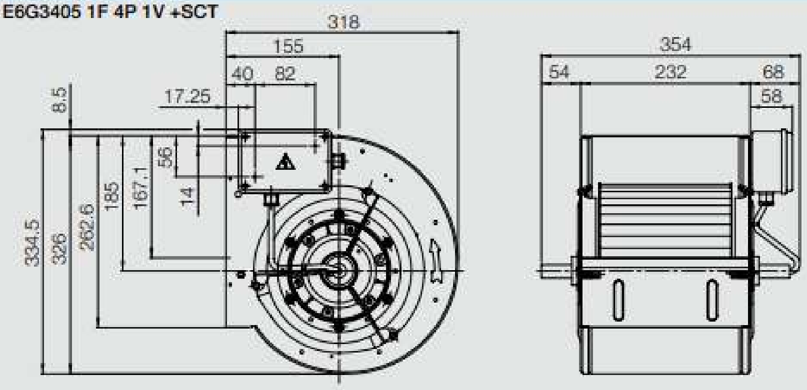


Figure 3.16 Evaporator fan dimension

3.9 Expansion Valve Selection

In the cooling system of the FE-PCA unit, a Danfoss brand thermostatic expansion valve will be used. The selection of the thermostatic expansion valve is based on the cooling capacity. The "Danfoss TGEL 10-6" model expansion valve will be used in the system. The technical specifications of Danfoss TGEL 10-6 are provided in Table 3.3.

Table 3.3 Technical specifications of Danfoss TGEL 10-6

Specifications	Descriptions
Gas	R410A
Connection	Welded
Balance	External Balance
Features	Two-way
Connection size	5/8" x 7/8"
Capacity Tonnage	6,5
Capacity (KW)	24
Orifice	Fixed

3.10 Liquid Receiver Selection

Selection of the liquid receiver is made based on the cooling capacity/volume graph shown in Figure 3.17.

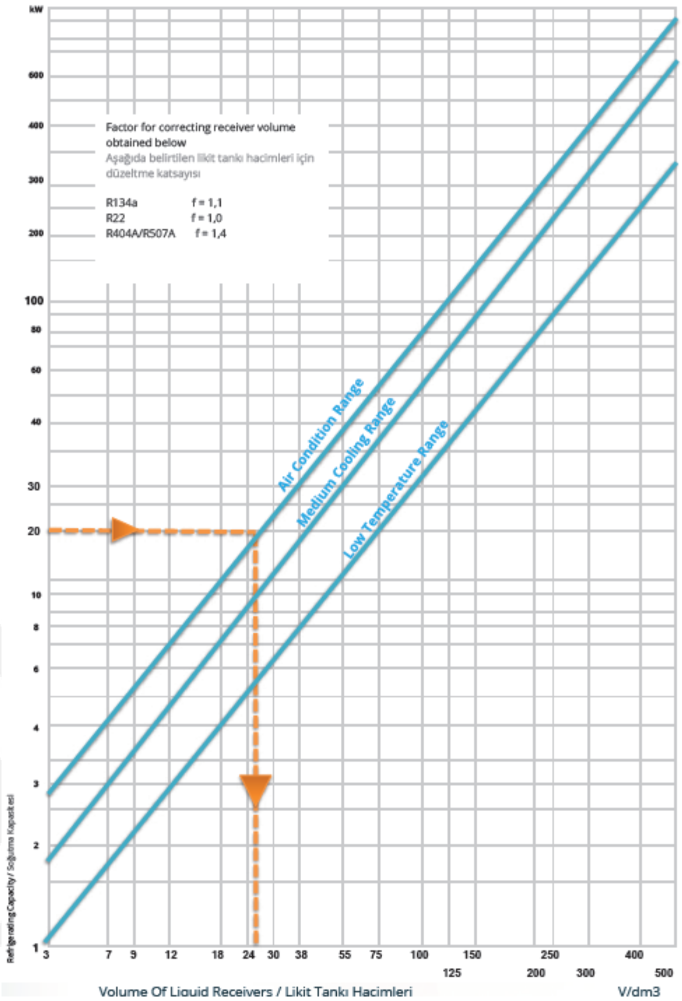


Figure 3.17 Cooling capacity/volume graph for liquid receiver

Based on this graph, a liquid receiver with a sufficient volume will be suitable for a cooling system with cooling capacity. The selected liquid receiver is the GVN brand, model V6A.33b.07.A2.A2.F4, with technical specifications provided in Figure 3.18.

Volume [Lt]	Model	ø D [mm]	L [mm]	L1 [mm]	L2 [mm]	Support [F]	Inlet [1]	Outlet [2]	NPT [3]	Kg Of Capacity R22	R134a	R407C	R404A	R410A
4	V5A.33b.04.A2.A2.F4		325							4,4	4,4	4,2	3,8	3,9
5	V5A.33b.05.A2.A2.F4	ø 140	395			V135-03				5,4	5,5	5,2	4,8	4,9
6	V5A.33b.06.A2.A2.F4		475							6,5	6,6	6,3	5,8	5,8
7	V6A.33b.07.A2.A2.F4		390							7,6	7,7	7,3	6,7	6,8
8	V6A.33b.08.A2.A2.F4		460	90	120					8,7	8,8	8,3	7,7	7,8
9	V6A.33b.09.A2.A2.F4		510				1"	1"		9,8	9,9	9,4	8,6	8,8
10	V6A.33b.10.A2.A2.F4	ø 165	550			V162-03				10,9	11,0	10,4	9,6	9,7
12	V6A.33b.12.A2.A2.F4		660							13,1	13,2	12,5	11,5	12,7
14	V6A.33b.14.A2.A2.F4		770							15,2	15,4	14,6	13,4	13,6
16	V6A.33b.16.A2.A2.F4		870							17,4	17,6	16,7	15,4	15,6

Figure 3.18 Technical specifications of liquid receiver

3.11 Low Pressure and High Pressure Pressure Switches Selection

Low-pressure pressure switch is used at the evaporator outlet and compressor inlet to prevent liquid from entering the compressor and to protect the compressor from potential damage caused by liquid refrigerant.

The selected low-pressure pressure switch is "MATCHWELL 025G054G".

High-pressure pressure switch is used at the compressor outlet to prevent the pressure from rising excessively and causing damage to the system.

The selected high-pressure pressure switch is "MATCHWELL 580R464R".

3.12 Sight Glass Selection

Sight glass is connected to the line between the condenser outlet and the expansion valve. In this line, liquid refrigerant should flow towards the expansion valve as per the system installation requirements. If foaming is observed in the sight glass, it is necessary to check the gas quantity in the system.

The selected sight glass is "HONGSEN SGN-7/8".

3.13 Filter Selection

When selecting a filter, its efficiency, resistance against air flow and operating conditions should be taken into consideration. It will be sufficient to use a G4 filter in the suction direction of the evaporator. The dimensions and specifications of the selected G4 filter are provided in Table 3.4.

Table 3.4 Technical specifications of the G4 filter

Specifications	Values
Width x Height x Frame Depth	846 x 292 x 48 mm
Filter material	100% polyester synthetic fleece
Frame type	galvanized sheet
Filter class	according to EN 779: 2012: G4
Filter class	according to ISO 16890: ISO Coarse 70%
Degree of filtration	(Am):> 91.6%
Maximum working temperature	<100 ° C
Permissible relative humidity	<100%
Recommended final resistance	200 Pa

3.14 Resistance Selection

Calculation for the heating resistance to raise the outdoor air temperature from -15 °C to 12 °C will be performed. The technical specifications for the heating resistance are shown in Figure 3.19.

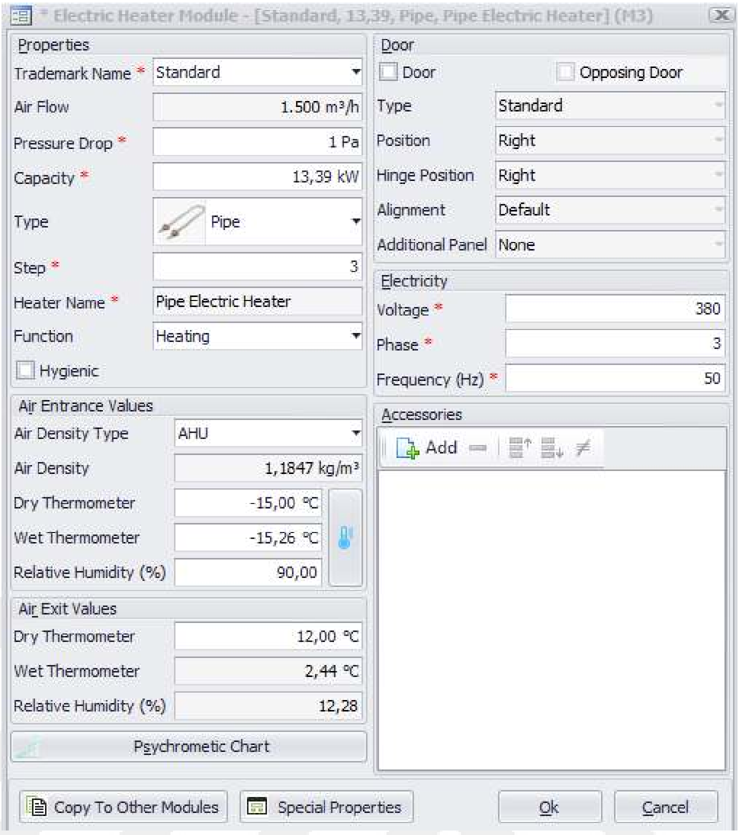


Figure 3.19 Technical specifications for resistance

Required capacity for the electric heater has been calculated as 13.39 KW. A configuration of 5 electric heaters, each with a capacity of 3 KW, will be used, totaling 15 KW.

3.15 Control Unit Selection

Programmable Logic Controller (PLC) is a technique resulting from general-purpose control and automation work carried out in various industrial applications. It has been decided to use PLC for the system automation of the FE-PCA unit. PLC stands out particularly in industrial applications due to its expandability, flexibility of analog modules and programming, built-in function blocks and ease of troubleshooting and repair. Siemens brand PLC will be used in the system, as it offers high CPU speeds, a variety of expansion modules and user-friendly software. Therefore, Siemens brand PLC has been chosen. PLC block diagram is provided in Figure 3.20.

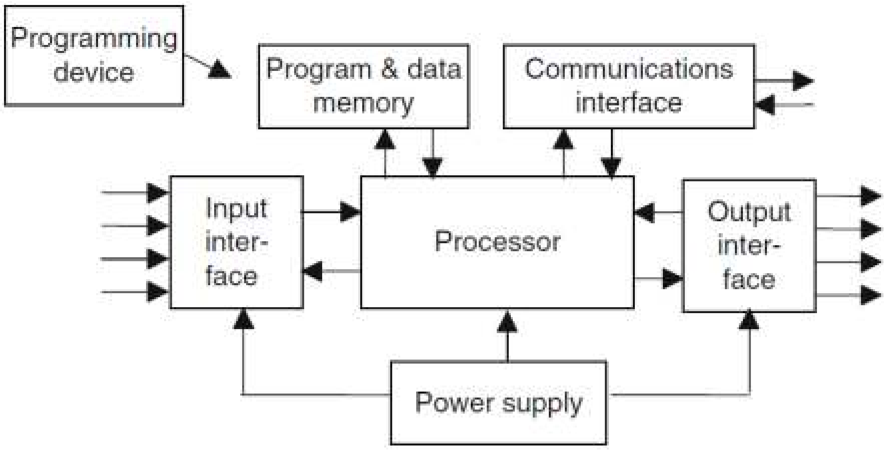


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Figure 3.20 Block diagram of programmable logic controller (PLC) [26]

Control panels are being assembled with the necessary components and drives in the system. A steel control panel with the dimensions of 400x400x200 mm, identified as EKO 110 040420, has been selected from the Tempa panel catalog as shown in Figure 3.21.

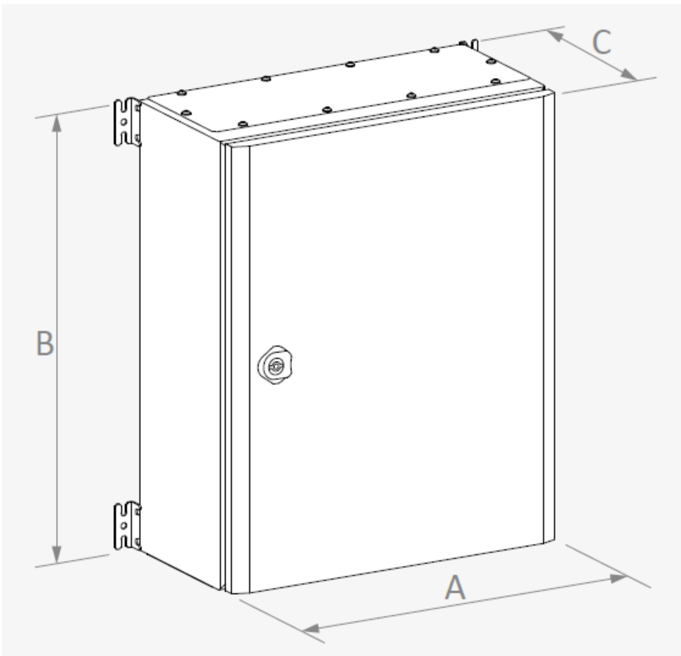

Figure 3.21 Control panel image

Siemens S7-300 Series CPU314 has been chosen as the modular PLC system developed by Siemens for medium-performance tasks, providing support for a wide range of commands during the programming phase. This CPU is preferred because it can fulfill the basic input/output configuration of the machine.

In the FE-PCA unit, a manual operator panel (see Figure 3.22), which is linked to its specifications, has been used The power supply for all control lines required for the drives has been selected as 24 Volt DC.

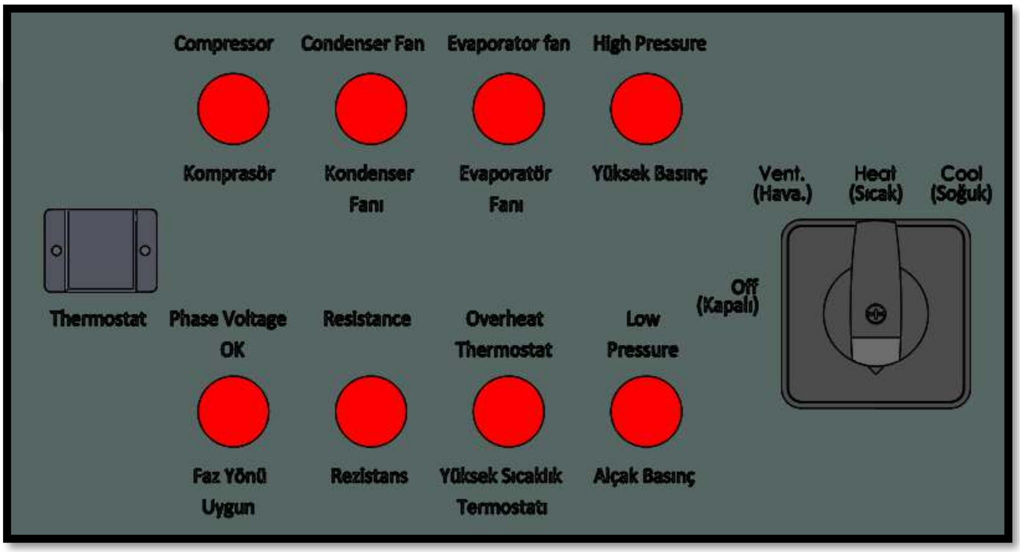

Figure 3.22 FE-PCA control panel

The control panel box displays the phase voltage ok, as well as the status of the evaporator and condenser fans, compressor, resistors and high and low-pressure warnings. Additionally, the panel allows adjustment of the system's hot, cold and off positions and the thermostat connection input is also located in this area. Inside the electrical panel, there will be a dedicated board for connecting temperature and pressure sensors. All electrical connections will be consolidated within this panel.

CHAPTER 4

UNIT DESIGN

4.1 Design Criteria for the Unit

After identifying the needs during the preparatory process, the design boundaries where the cooling fluid system will be located were initially defined according to the constraints imposed by the system components. A Computer-Aided Design (CAD) program was used to facilitate the product design. Thanks to the program, it was possible to design the unit in a virtual environment before manufacturing. In the final stage, the model was analyzed and tested for its safety. After component selection based on the requirements, the design phase was completed and structural analysis was performed to determine the necessary force locations and test the model's safety. Nowadays, there are many advanced CAD programs with various features and modules available. In this study, the SolidWorks 2021 program was used for product design and the Ansys Workbench 2023 program was used for the analysis process.

The Mobile FE-PCA unit has been designed to meet all the requirements in terms of design and manufacturability. During the detailed design phase, the assembly sequence of the parts has been taken into consideration, aiming to achieve the most suitable design for manufacturing. If desired, a design concept suitable for mass production has been developed. In order to protect the unit from environmental factors and enhance corrosion resistance in susceptible areas, appropriate coating and painting processes will be applied in addition to material selection. Pre-painting surface preparation and primer coating will be carried out.

Designs that could create stress concentrations have been avoided and necessary precautions have been taken. Material assignments and dimensioning have been carried out for the parts created during the design process. At the end of the design, a mobile PCA unit with dimensions of 938 x 1267 x 1914 (mm) has been obtained. In Figure 4.1 and Figure 4.2, depict external views of the FE-PCA unit from different directions.

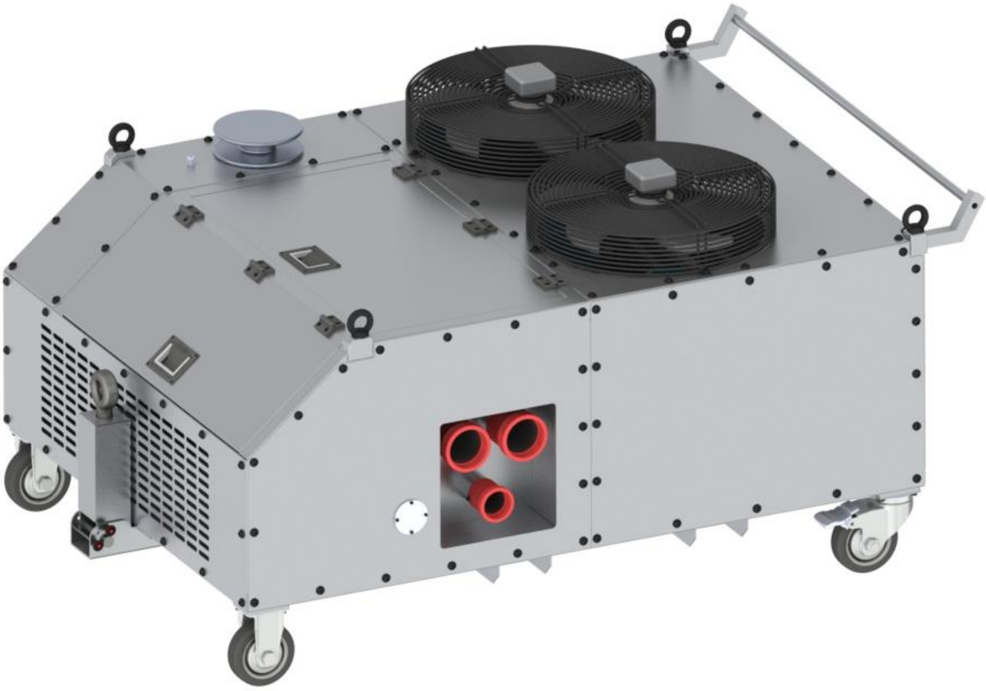

Figure 4.1 Exterior view of the mobile FE-PCA unit (left side)

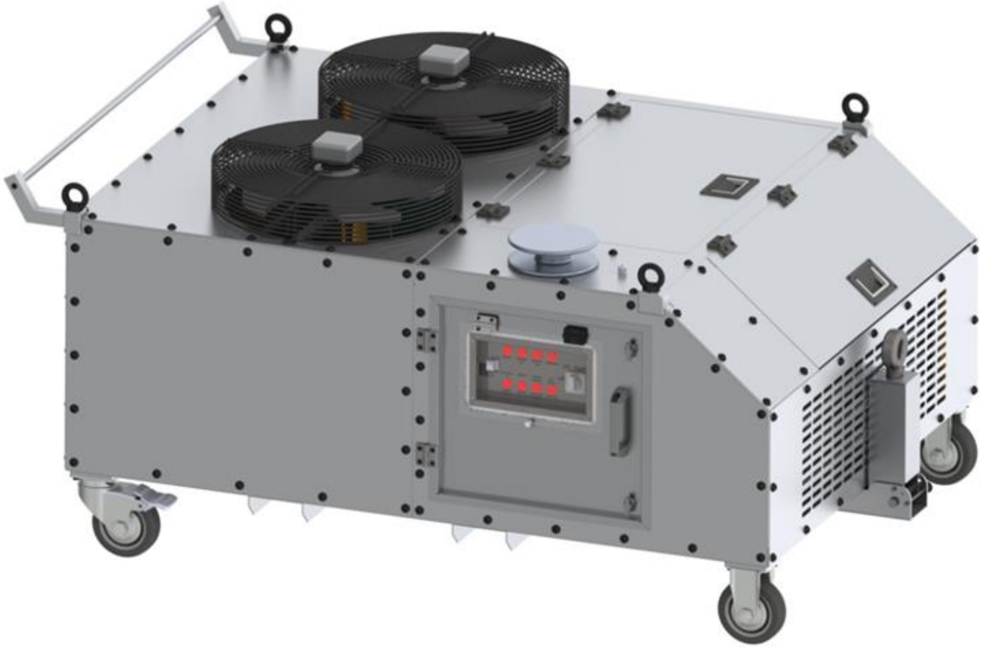

Figure 4.2 Exterior view of the mobile FE-PCA unit (right side)

In the front section of the unit, condenser, centrifugal fan, air ducts, electrical panel, flexible hoses are located, while in the rear section, compressor, liquid tank, condenser and axial fans are positioned. In Figure 4.3, shows the inside view of the unit.

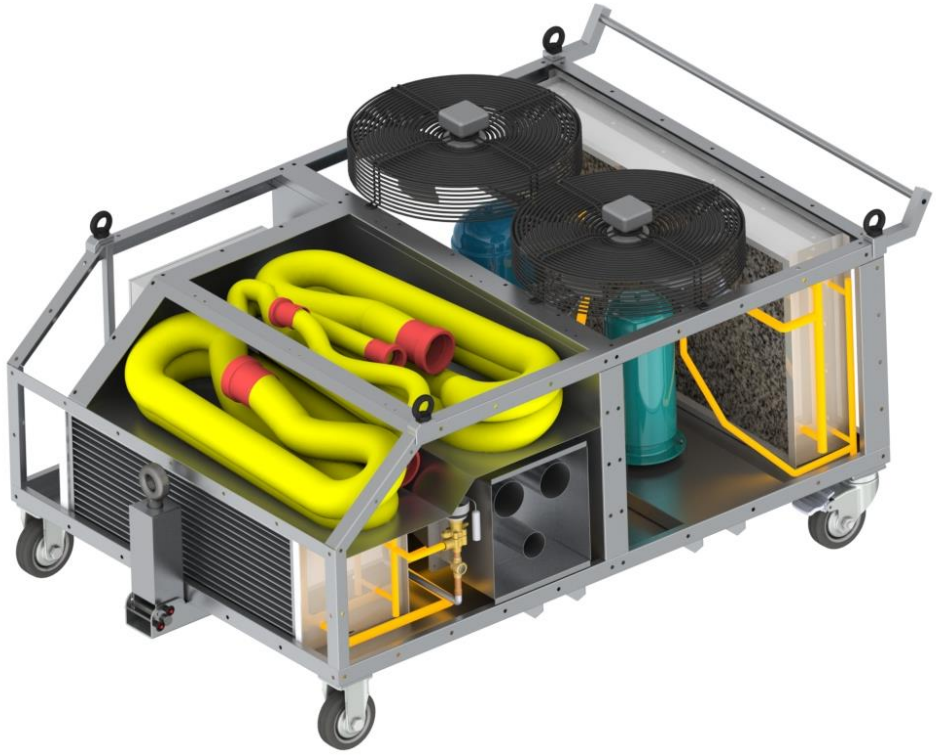

Figure 4.3 Interior view of the mobile FE-PCA unit

4.2 General Design Features

Type of PCA units selected for an aircraft is determined considering the heating and cooling requirements after the performance requirements are known during the design and planning phase. The design aims to achieve the most suitable design based on factors such as energy efficiency, emissions, environmental conditions, space utilization, operational efficiency and cost. The FE-PCA model is a high-capacity Pre Conditioned Air (PCA) device with special systems that allow it to operate in harsh environmental conditions. It can be manually operated or towed by any vehicle, enabling rapid and safe transportation to the desired location. With specially selected wheels, it can move on various terrains. It is suitable for air, land or sea transportation.

The mobile PCA unit should be designed with a corrosion-resistant structure by applying suitable coating and painting processes. Extreme environmental conditions such as sand, dust, rain, snow, hail, salty air and wind should not hinder the functioning of the system. These units should withstand not only environmental hazards but also transportation to the field. The system components are mounted on a structurally robust steel chassis. The choice between hot air or cold air can be adjusted from the control box inside the unit, making it a fully automatic device that can be used safely. Additionally, energy efficiency and environmental considerations play an important role in determining whether the PCA units used in an aircraft will be diesel engine-driven or electric. Electric PCA units are increasingly becoming more common as they comply with aviation regulations for environmental protection. Electric PCA units are also more efficient in terms of energy efficiency. Therefore, the working principle preference for the mobile FE-PCA unit is electric.

4.3 Design Purpose and Features

A portable heating and cooling unit has been designed to maintain optimal temperature levels for avionics during maintenance, repair and ground control operations of an unmanned combat aerial vehicles. The designed ground support device is a completely custom and innovative next-generation ground support system specifically designed for the heating and cooling needs of the aircraft. The heating and cooling system can draw its energy from the local power grid or a generator located in the operating area**.**

4.4 Design Features

- Durable steel chassis (S235JR) resistant to environmental conditions, vibrations and impacts.
- Covers used to provide easier access to the components inside the unit during assembly and maintenance are made of aluminum 5754 series, which offers advantages in terms of weight, bendability, and is widely used in land platform units.

- To protect the unit from corrosion and different weather conditions, the following coating and painting processes will be applied:

    - For aluminum materials: Chromate conversion coating (yellow) according to MIL-DTL-5541F standard, primer paint according to MIL-DTL-53022E standard, topcoat paint according to MIL-DTL-53039E standard (RAL 9003 - Signal white) and some covers in (RAL 7035 - Light grey).
    - For steel materials: Zinc phosphate coating according to MIL-DTL-16232G standard, primer paint according to MIL-DTL-53022E standard, topcoat paint according to MIL-DTL-53039E standard (RAL 9003 - Signal white).
    - For stainless steel materials: Passivation treatment will be applied according to ASTM A967-05 standard.

- Mobil FE-PCA unit is designed to be suitable for transportation by land, air and sea, including provisions for manual transporting with a hand push rod for human transport, four eye bolt for crane lifting and lowering and lifting zone for transportation with a forklift. In Figure 4.4, shows the four mounting eye bolt installed on the unit.

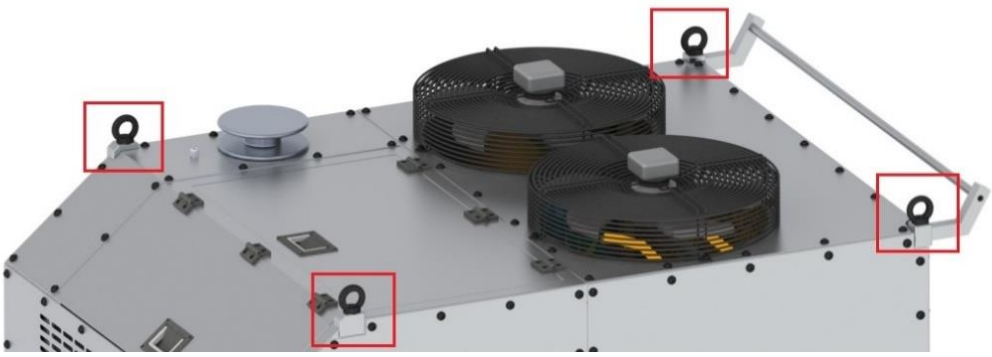

Figure 4.4 The positioning of eye bolt in the unit

- The unit is designed to be easily transported to different locations with the help of special pins (Elesa Ganter GN 114.3 model) and a portable structure equipped with a towing bar that allows for three different adjustments (see Figure 4.5). The specially designed towing arrow provides advantages in terms of versatility and usability, enhancing its overall functionality.

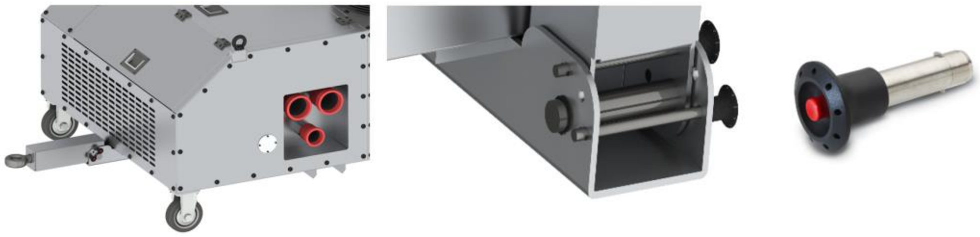

Figure 4.5 Adjustable tow bar

- Heating and cooling capacity can be adjusted incrementally or fixed with a thermostat control that preserves energy efficiency, preventing unnecessary energy consumption

- The system is equipped with a G4 filter protection and in Figure 4.6, shows the placement of the filter in front of the evaporator.

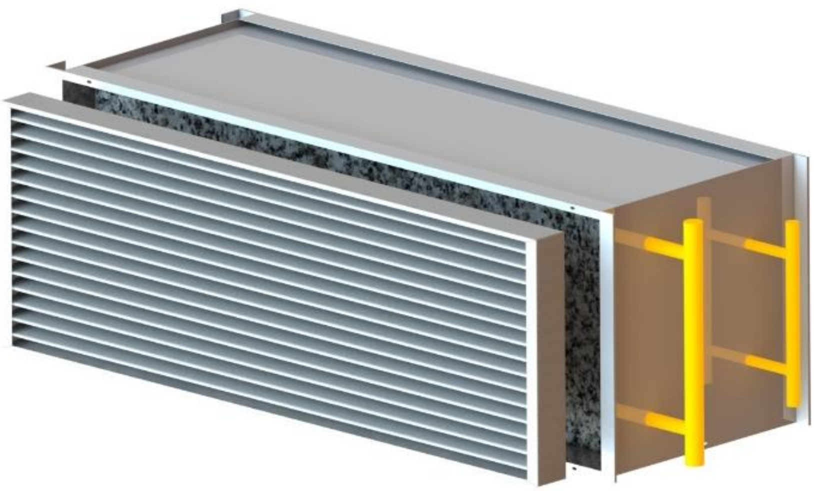

Figure 4.6 G4 filter positioning

- Specially designed hose nozzle for easy connection (see Figure 4.7)

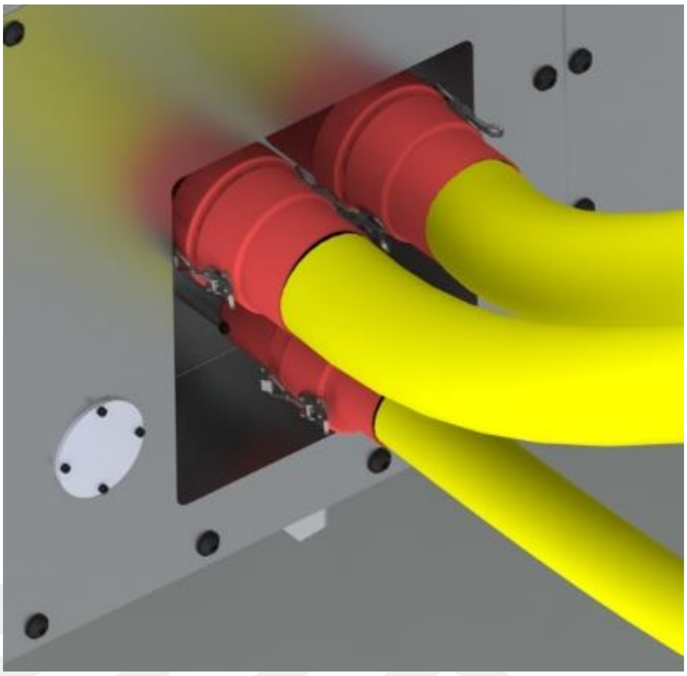

Figure 4.7 Special design hose nozzle

- The unit has a closed cabinet where flexible hoses can fit (see Figure 4.8).

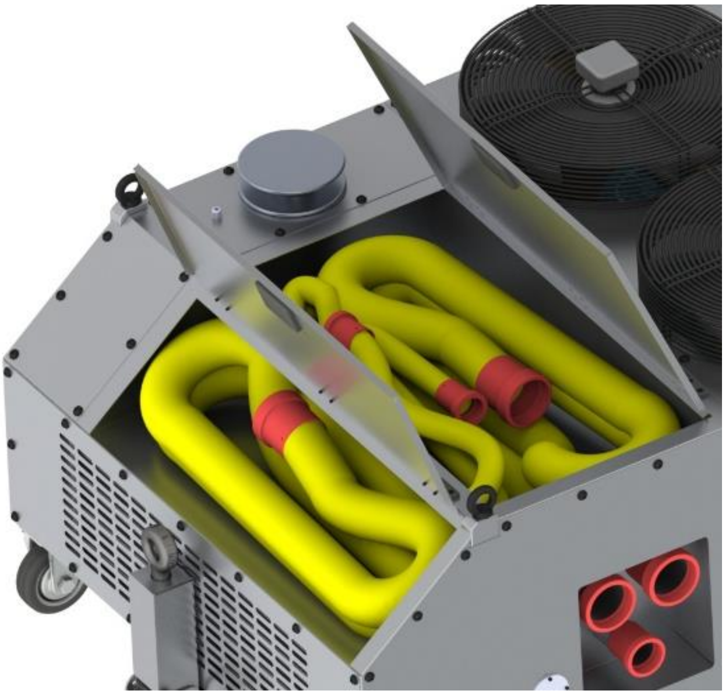

Figure 4.8 Covered flexible hose enclosure

- Display panel and its cover of the FE-PCA unit are shown in the figure. The electrical panel, where the panel is mounted, is compliant with IP65 standards, ensuring a waterproof structure (see Figure 4.9).

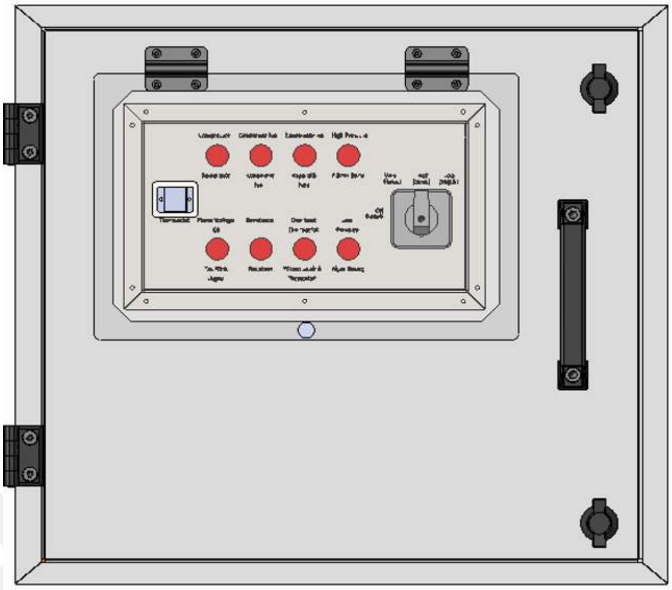

Figure 4.9 Display panel and cover of the FE-PCA unit.

- It has the ability to monitor the system level from outside with a sight glass and has three air hose outlets 2xØ90 and 1xØ60 mm (see Figure 4.10).

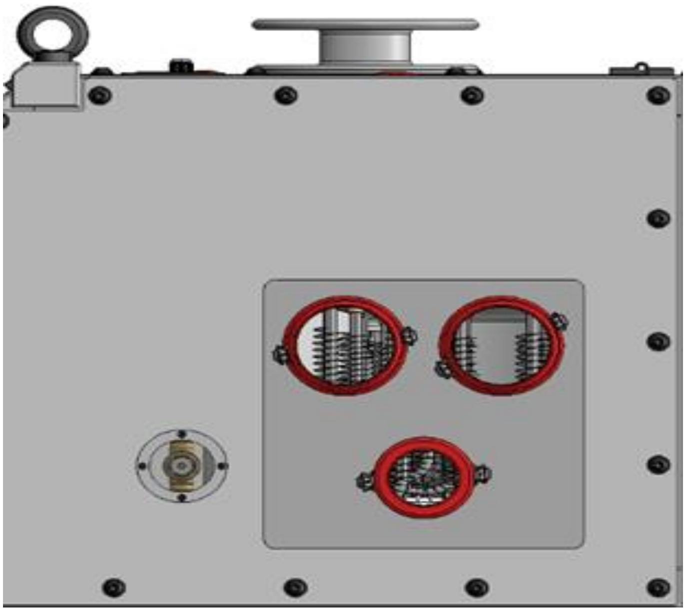

Figure 4.10 Sight glass and air outlet zone

- There is a 10 meter power cable winding device (see Figure 4.11).

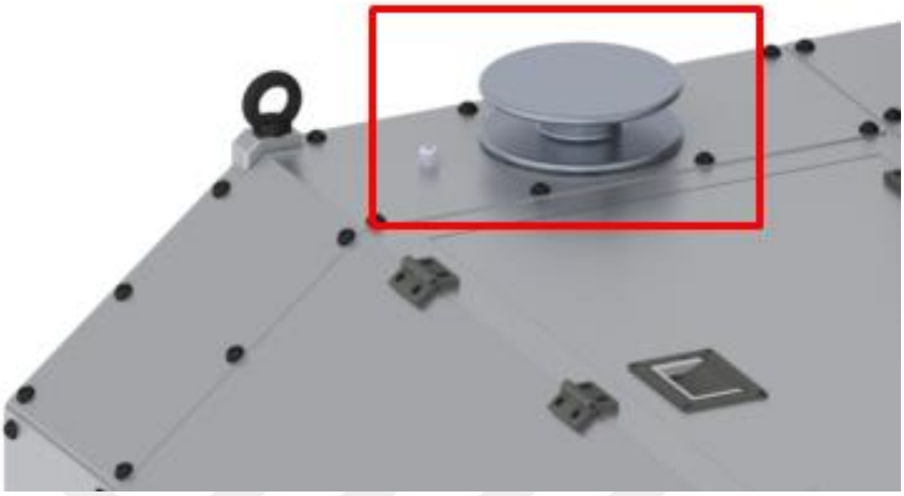

Figure 4.11 Cable winding apparatus

- To prevent the accumulation of rainwater or any other liquids in necessary areas, an example of a drainage hole for water ingress into the unit is shown in Figure 4.12.

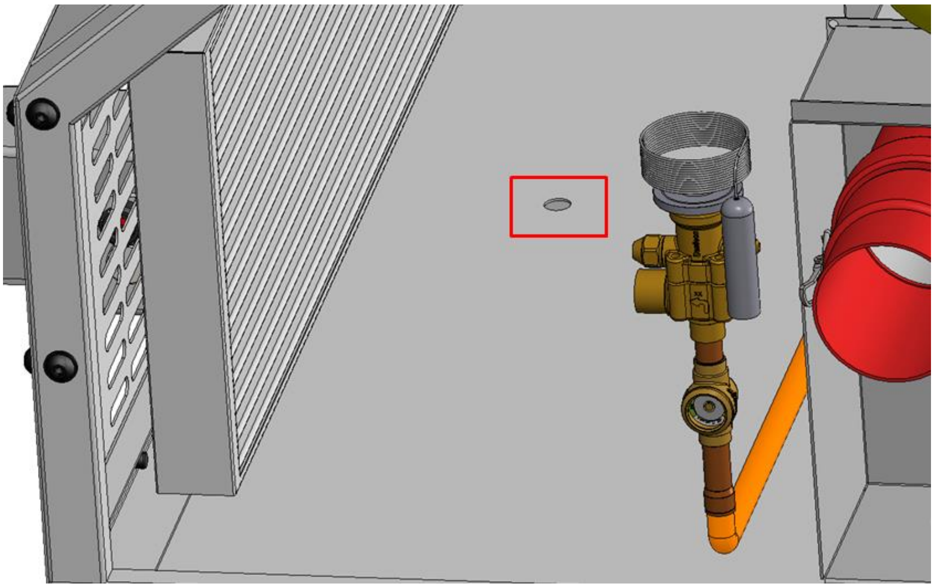

Figure 4.12 Drainage hole area

- A spring-loaded design has been implemented to protect the towing bar from various deformations (see Figure 4.13).

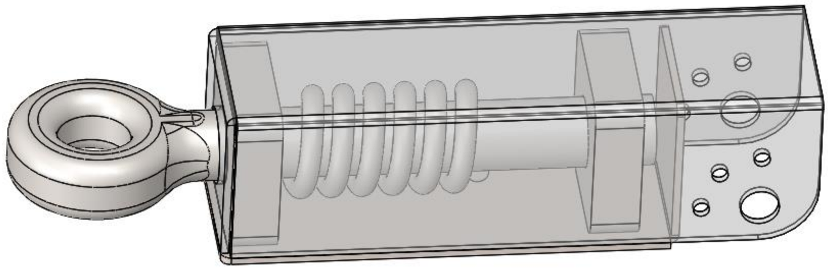

Figure 4.13 Tow bar interior view

- High and low-pressure protection, electrical protections and over-temperature protection.

The general technical specifications of the Mobile FE-PCA Unit are provided in Table 4.1.

Table 4.1 Design features of mobile FE-PCA unit

Features	Values
Device Dimensions	938 x 1267 x 1914 mm (When the tow bar is extended 2255)
Device Weight	338 kg
Chassis	S235JR (ST37-2)
Covers	AL-5754

In Figure 4.14, a representative image of the Mobile FE-PCA Unit and the General Atomics MQ-1 Predator used by the United States Air Force is shown.

Figure 4.14 Representational image of the mobile FE-PCA unit together with the MQ-1 Predator.

4.5 Chassis Design and Specifications

All vehicles have a body that carries their own weight and the load they carry. The chassis in a vehicle is the component that carries all the weights in the system. Depending on the application and objectives of the chassis, it needs to have various mechanical features. When designing a chassis, attention is given not only to the type of material but also to the selection of raw material. Concepts such as manufacturing type, weight, cost, resistance to torsion and bending can vary depending on the type of raw material. In terms of its welding capability, structural strength, economic characteristics and ease of procurement, S235JR (ST37-2) material, which belongs to the structural steel class, has suitable mechanical and heat treatment properties for chassis design. Detailed information on S235JR can be found in the analysis section of the comprehensive thesis.

Within the scope of the thesis, a chassis type consisting of sturdy L-bracket bent parts, which can be easily shaped and allows for easy design changes, has been considered. To create a durable chassis structure, bending processes have been applied to flat parts and the attachments used for component connections in the subframe have provided strength to the chassis.

The L-brackets used will be connected to each other using TIG welding. The designed chassis consists of the sub-chassis assembly, upper-chassis assembly, middle-chassis assembly, tow bar connection, component support parts, forklift lift zone, hand push rod, eye bolt connection part and wheel mounting plate (see Figure 4.15). The system components are positioned on the sub-chassis assembly. The presence of the middle support frame has resulted in a structure resistant to torsional rigidity.

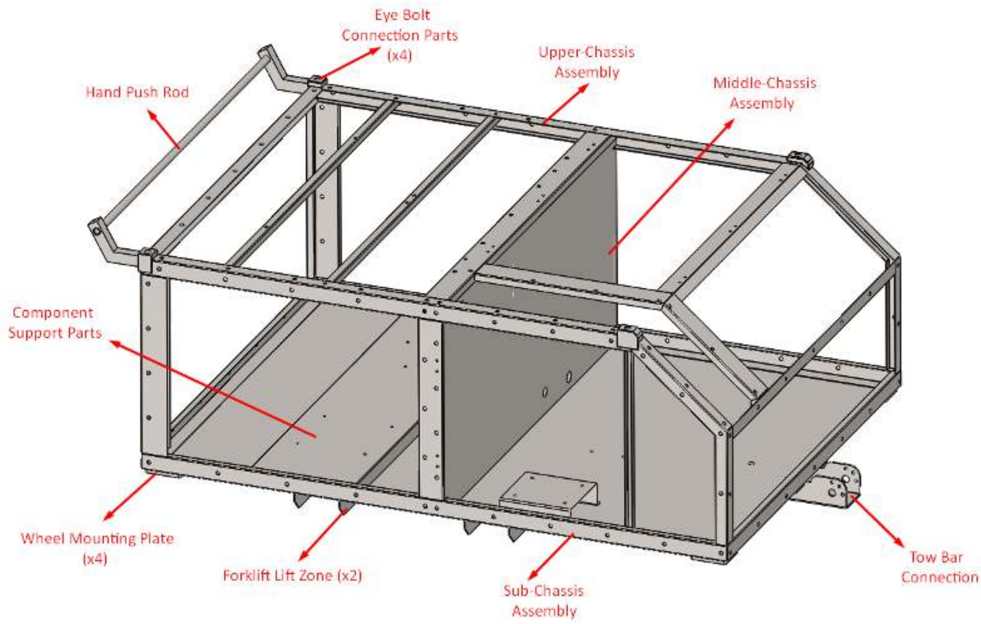

Figure 4.15 Welded chassis structure of the mobile FE-PCA unit

When designing a chassis, attention must be paid to its strength, resistance to bending and torsion. The lower base support plates have provided the chassis's lower section with a highly durable structure. The middle chassis ensures a solid connection between the sub and upper chassis. The dimensions of the unit are adjusted on the used chassis according to the sizes of the components that will be placed on it. The chassis can be scaled down or enlarged based on the conditions and component dimensions, if desired. As the chassis is manufactured using a welding process, welding templates will be created in necessary areas, taking into account the material distortion and in some regions, holes will be drilled using special welding templates to prevent tolerance deviations.

4.6 Unit Assembly

Connections between the components in the Mobile FE-PCA unit are made using either bolt-nut assembly or welding methods. As the unit is portable, the assembly of the parts is crucial to withstand vibrations. The unit dimensions are designed to accommodate the connection of components. The exploded view of the main parts of the unit obtained through the 3D computer-aided design is shown in Figure 4.16. The unit consists of the following general sections:

1. Unit Covers
2. Chassis
3. Tow Bar
4. Wheel Set
5. Control Panel
6. Internal Support Parts
7. Refrigerant System
8. Hand Push Rod

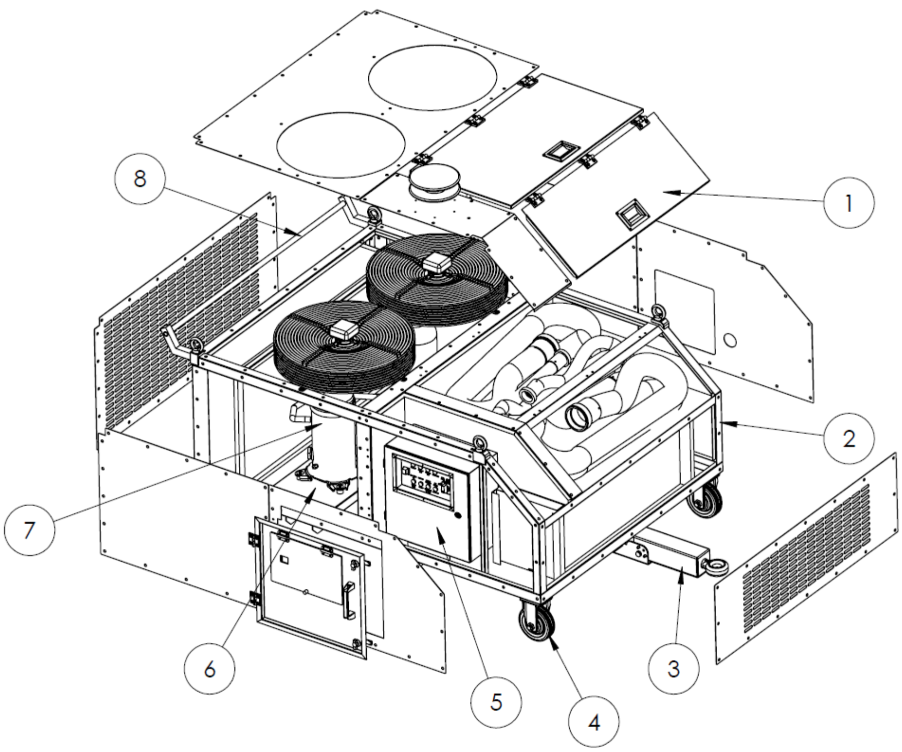

Figure 4.16 Exploded view of the mobile FE-PCA unit

As seen in the Figure 4.16, a unit has been designed with dimensions of 938 x 1267 x 1914 (mm). With these dimensions, the components can be assembled in accordance with the structural configuration of the unit.

- In areas where the entry of liquids, rain and moisture into the unit is undesired, sealing is attempted using gaskets. The material used in the frame of the covers and in certain internal areas of the unit is EPDM, which is a commonly used sealing material in various industries. An example of the assembly of the cover and EPDM gasket can be seen in Figure 4.17.

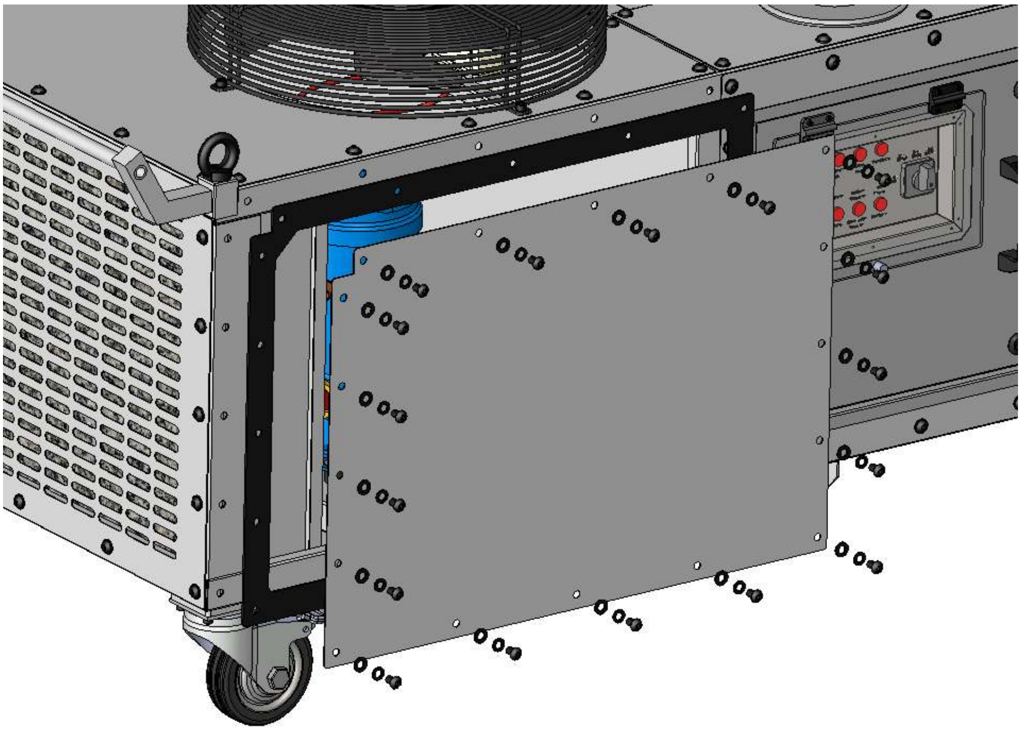

Figure 4.17 Cover gasket assembly illustration

- The assembly of the centrifugal fan and sheet metal air duct components is shown in Figure 4.18.

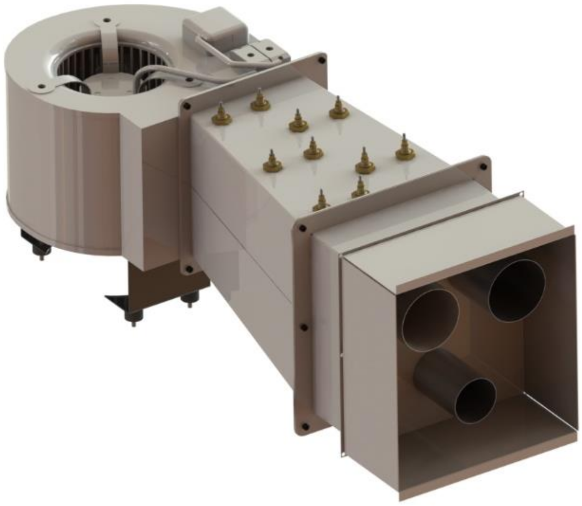

Figure 4.18 Assembly of centrifugal fan and air duct components

- Installation of 5 serpentine resistances, which will be used for heating the unmanned aerial vehicle when needed, into the air duct, is shown in Figure 4.19.

Figure 4.19 Assembly image of serpentine resistances

- Some system components such as compressor, liquid receiver, centrifugal fan, etc., are positioned on the chassis using anti-vibration rubber bolted wedge, reducing component vibrations to a minimum (see Figure 4.20).

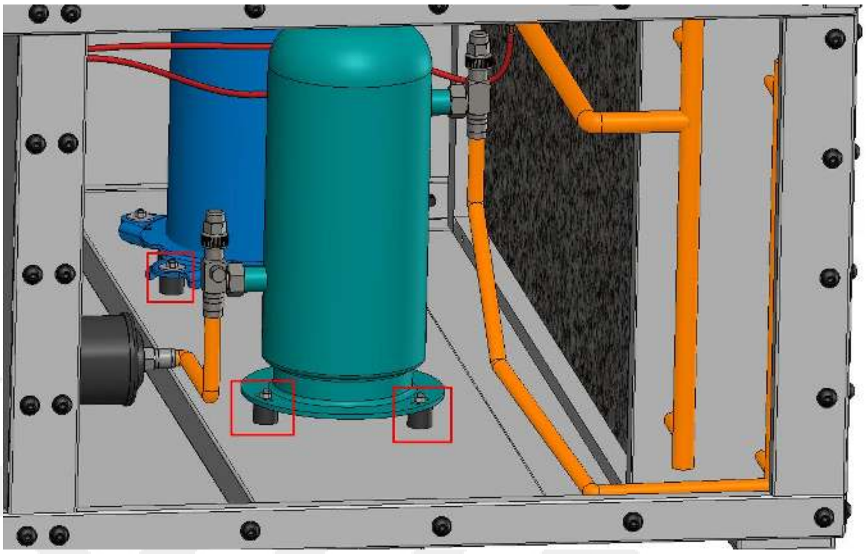

Figure 4.20 Placement of rubber bolted wedge used for components in the unit

- Wheels were selected for maneuvering movements and ease of transportation with Kama brand front fixed wheels in Figure 4.21 and rear movable wheels in Figure 4.22. These wheels were determined to meet the carrying capacities of the FE-PCA unit.

3307 SLP

ÜRÜN KODU	mm	mm	mm	mm	mm	mm	kg
3307 SLP 080	80	25	108	100x85	80x60	17x9	50
3307 SLP 100	100	30	128	100x85	80x60	17x9	70
3307 SLP 125	125	37.5	154	100x85	80x60	17x9	100
3307 SLP 150	150	40	180	100x85	80x60	17x9	125
3307 SLP 200	200	50	240	140x110	105x75-80	13.5x11	205

Figure 4.21 3307 SLP 150 fixed wheel

3302 SLP F18

ÜRÜN KODU	mm	mm	mm	mm		mm	mm	mm	kg
3302 SLP 080 F18	80	25	108	43	125	100x85	80x60	17x9	50
3302 SLP 100 F18	100	30	128	41	125	100x85	80x60	17x9	70
3302 SLP 125 F18	125	37.5	154	38	125	100x85	80x60	17x9	100
3302 SLP 140 F18	140	37.5	177	38	120	100x85	80x60	17x9	115
3302 SLP 150 F18	150	40	180	37	125	100x85	80x60	17x9	125
3302 SLP 160 F18	160	38	199	54	150	140x110	105x175-80	13.5x17	135

Figure 4.22 3302 SLP 150 F18 movable wheel

4.7 Assembly Connections

Different types of stainless steel bolts, washers and spring washers were used for securing system components to the mobile unit and for joining certain mechanical parts together. An example of the assembly method using a bolt, washer, spring washer and rivet nut for the cover chassis connections is shown in Figure 4.23. Washers were used to prevent damage to the unit's paint during the tightening process of screws and nuts. In areas where vibration may occur, spring washers were used to absorb vibrations and ensure secure connections.

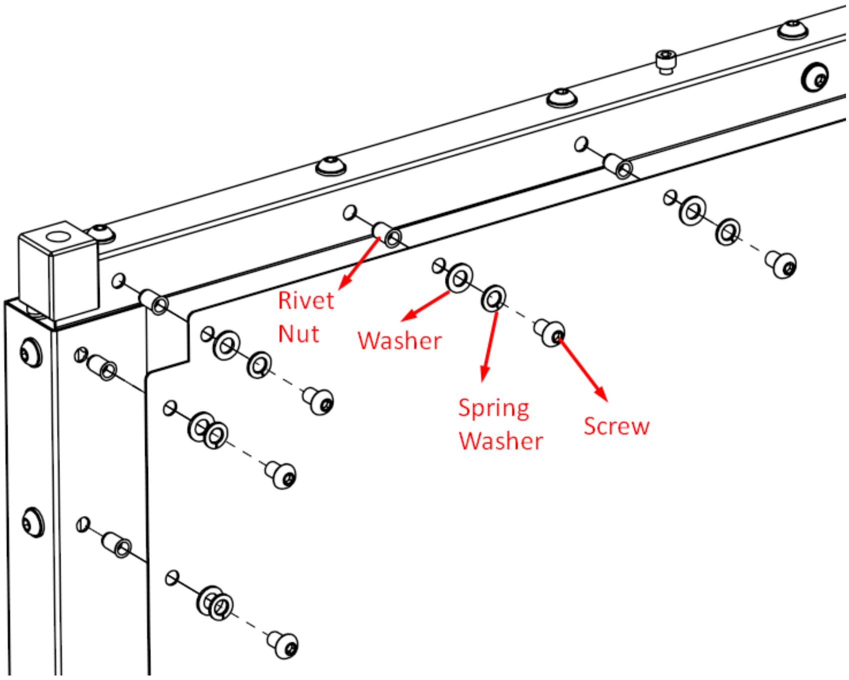

Figure 4.23 Example image of cover-chassis assembly elements

4.8 Welded Assembly of the Unit

During the process of welded assembly, welding joint symbols were attempted to be used based on the thickness of the parts to be welded and to minimize deformation. Welding fixtures will be employed for all main surfaces of the unit to ensure that the hole centers do not shift and to achieve the best possible tolerance in production. The welded joints will be made using TIG welding. The assembly of covers and lock-hinge systems in the welded structure will be done using screw-nut connections. Welding indications in certain areas are shown as in Figure 4.24. In areas where welded connections are not necessary, the method welding approach will be applied instead of continuous welding to reduce deformation. In the welding of the copper pipes in the system, first, the pipes are heated up to a certain temperature and then the welding process is carried out by applying heat to the appropriate solder wire using a welding torch.

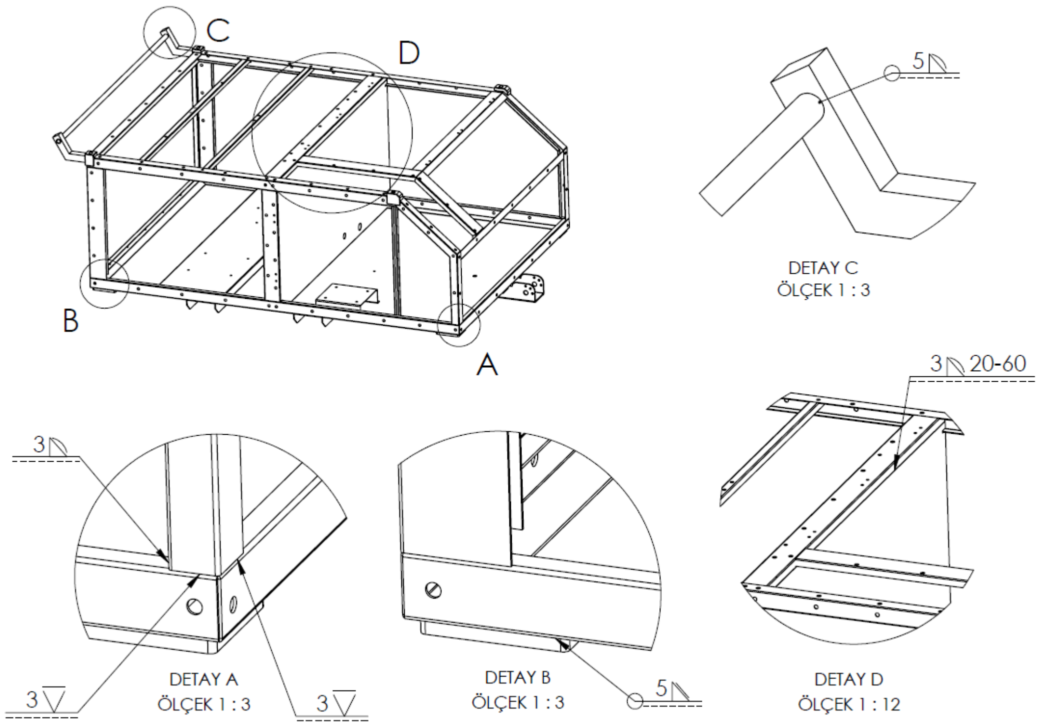

Figure 4.24 Sample weld symbols representations for the chassis

CHAPTER 5

STRUCTURAL ANALYSIS OF THE UNIT

Structural analysis demonstrates whether a system is in balance and mechanically safe under the load it is subjected to during a walking cycle. To determine deformations, equilibrium conditions and stress distribution at critical points in the structure, structural analyses were performed using the Ansys program. This analysis aims to determine the mechanical safety and durability of the structure throughout its operating cycle. After the final design is created, static load types are applied by creating analysis models in the Ansys Workbench 2023 program to evaluate whether their strengths are sufficient.

The selection of chassis material and the analysis model of the chassis using the finite element method, as well as the boundary conditions, are explained in the following headings.

5.1 Chassis Structural Analysis

5.1.1 Finite Element Method

Finite element method is a numerical technique that involves the computer-aided solution of a system being manufactured, incorporating its elements, connections, material information, contact definitions between components and boundary conditions using the finite element method. This method can be applied in various fields such as mechanical problems, fluid dynamics, heat transfer and many others. The finite element method offers many advantages for the analysis of products with either simple or complex geometries. In reality, due to the complex nature of physical problems, theoretical solutions can sometimes be inadequate. Therefore, the finite element method allows for the comparison of result data obtained from experimental methods, resulting in similar values.

Certain parameters or dimensions can be made parametric, allowing for quick and practical solutions in analyses. Therefore, the analysis programs used reduce engineers' time and engineering costs. Nowadays, there are numerous computer-aided engineering (CAE) programs available. The CAE programs based on the finite element method are referred to as finite element analysis (FEA) programs. The finite element method is considered advantageous for the analysis of products with regular or complex geometries.

In this study, the finite element model required for the analyses was created using the SolidWorks 2021 software, and the analysis studies were performed using the finite element method in the Ansys Workbench 2023 software.

5.1.2 Design and Material Information

Within the scope of the thesis, a mobile FE-PCA unit has been designed, consisting of a chassis made of S235JR structural steel and twisted plates. An aesthetic chassis has been attempted to be created by combining multiple twisted and support plates.

From a commercial standpoint, by making small changes to certain parts, potential customers can be offered different mobile PCA designs based on the same underlying design. The reason for opting for twisted plates instead of profiled sections in the chassis is to achieve design alignment with the assembly connections of system components, reduce weight, facilitate shaping and minimize unnecessary costs. The chassis has been designed to be towed by towing vehicles such as towing vehicles and forklifts.

The designed chassis consists of a main structure, push handle, component mounting plates, wheel mounting plates and tow bar connection sections. The twisted metal plates will be joined together using TIG welding.The visual representation and dimension information 735x1235x1914 (mm) of the designed chassis are shown in Figure 5.1.

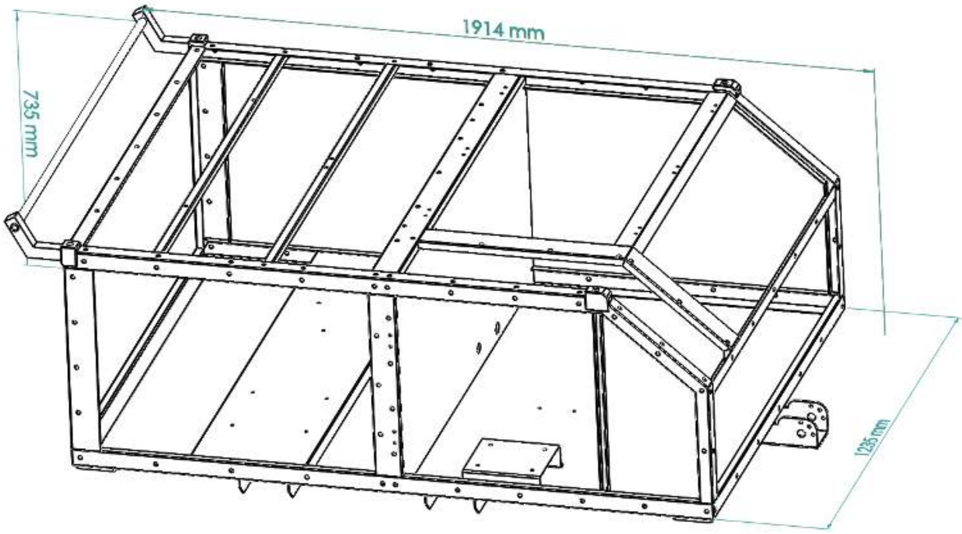

Figure 5.1 The designed chassis and its dimensions

5.1.3 Material Section

Chassis material of the designed unit is S235JR (DIN-ST37-2), which is a widely used hot-rolled structural steel in various industries such as construction and manufacturing. It has been chosen as the preferred option in the chassis design of the unit due to its high formability properties such as bending, plasticity, toughness and weldability, as well as its high strength and suitability for cold forming.

These steels, such as S235JR, are commonly used for components and welded structural parts that have general requirements, including connecting rods, pins, shafts, screws, nuts, supports, stands, bridges and more. The main reasons for their widespread use in welded constructions are their lower cost compared to other steels, ease of availability and their ability to provide smooth and durable welds [27] . The "S" designation refers to "structural steel" with a yield strength of 235 MPa. The "JR" designation confirms that the material has passed the Charpy V-notch impact test at 27 joules at room temperature.

The mechanical compositions of the S235JR material used in the chassis are given in Table 5.1 and its chemical properties are provided in Table 5.2.

Table 5.1 The mechanical properties of grade S235 [28]

#	Minimumyield strength[MPa]						Tensile strength Rm[MPa]		Minimum elongation - A Lo = 5.65 * √So (%)				Notch impact test	
Steel grade	**Nominal thickness[mm]**						**Nominal thickness [mm]**		**Nominal thickness[mm]**				**Temperature**	**Min. absorbedenergy**
	≤16	>16 ≤40	>40 ≤63	>63 ≤80	>80 ≤100	>100 ≤125	>3 ≤100	>100 ≤125	>3 ≤40	>40 ≤63	>63 ≤100	>100 ≤125	[°C]	[J]
S235J0	235	225	215			195	360-510	350-500	26	25	24	22	0	27
S235J2	235	225	215			195	360-510	350-500	26	25	24	22	-20	27
S235JR	235	225	215			195	360-510	350-500	26	25	24	22	+20	27

Table 5.2 The chemical composition of grade S235 [28]

#	Ladle analysis												
Steel grade	C max.[%]			Mn max. [%]	Si max. [%]	P max.[%]	S max.[%]	N max.[%]	Cu max. [%]	Other max.[%]	CEV max.[%]		
	Nominal thickness [mm]										Nominal thickness [mm]		
	≤16	>16 ≤40	>40								≤30	>30 ≤40	>40 ≤125
S235J0	0.17	0.17	0.17	1.40	-	0.035	0.035	0.012	0.55	-	0.35	0.35	0.38
S235J2	0.17	0.17	0.17	1.40	-	0,030	0.030	-	0.55	-	0.35	0.35	0.38
S235JR	0.17	0.17	0.20	1.40	-	0.040	0.040	0.012	0.55	-	0,35	0.35	0.38

5.1.4 Constraints and Boundary Conditions

Constraints and boundary conditions are the terms used to describe the determination of the conditions under which finite element analysis takes place. This includes determining the applied forces on the structure and the locations of supports, among other procedures.

In the chassis model of the FE-PCA unit, the connection points are constrained in all degrees of freedom in space and boundary conditions are defined based on loading conditions on the chassis. Considering the operating conditions of the unit, the fixation boundary condition is chosen by selecting the wheel connection plates as the support points on the chassis and it is considered as a fixed connection, as shown in Figure 5.2.

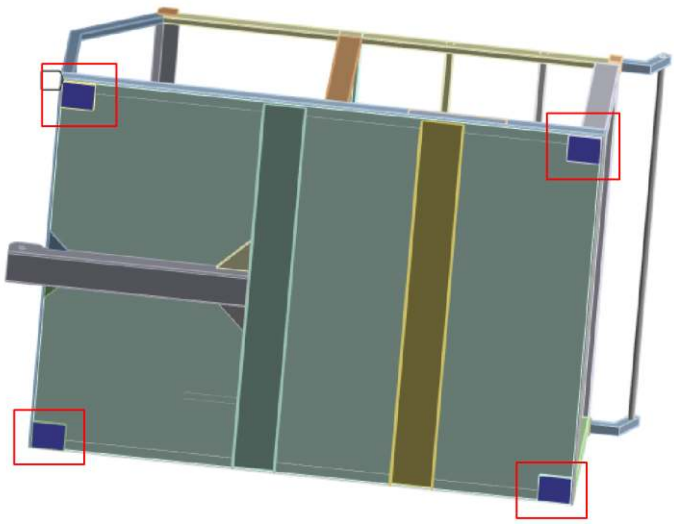

Figure 5.2 Representation of fixed support points

Before entering the necessary forces and boundary conditions for analysis, the CAD model has been divided into meshes to conform to the finite element method. The forces and moments applied to the chassis are positioned at the component connection areas located on the upper and lower chassis. For structural analysis, the material properties of structural steel S235JR, as mentioned above, have been entered.

5.1.5 Analysis of the Current Chassis

In this section, virtual analyses will be performed on the completed design of the chassis. Based on the yield strength value of the S235JR material used in the design, analysis stress values, deformation amounts and safety factors are shared in this section.

In the structure fixed by wheel connection plates, initially, the components placed on the chassis are subjected to forces applied perpendicularly and uniformly at the contact points between the components and the chassis (see Figure 5.3).

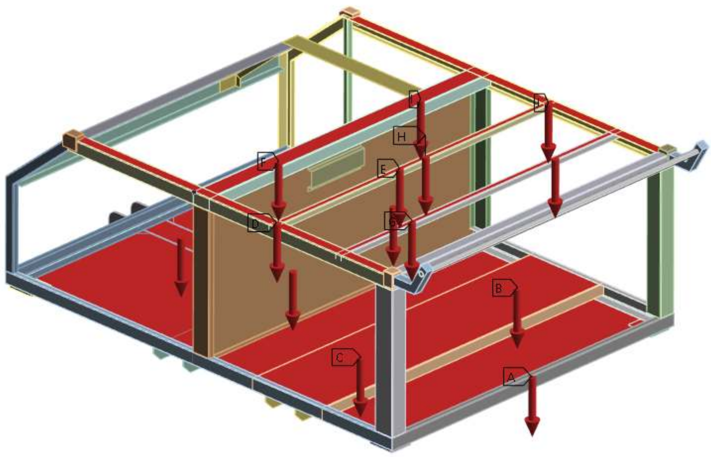

Figure 5.3 Contact points of the forces exerted on the chassis

According to the given color diagrams, the red regions represent areas where stress is higher compared to other regions. Conversely, the dark blue regions indicate the areas with the lowest stress. Subsequently, as stress increases, the colors progress from light blue to green, yellow and red, indicating increasing stress levels in those regions. The deformation values of the chassis resulting from the applied static load are shown in Figure 5.4. It is observed that the maximum deformation occurs in the base plate section of the chassis.

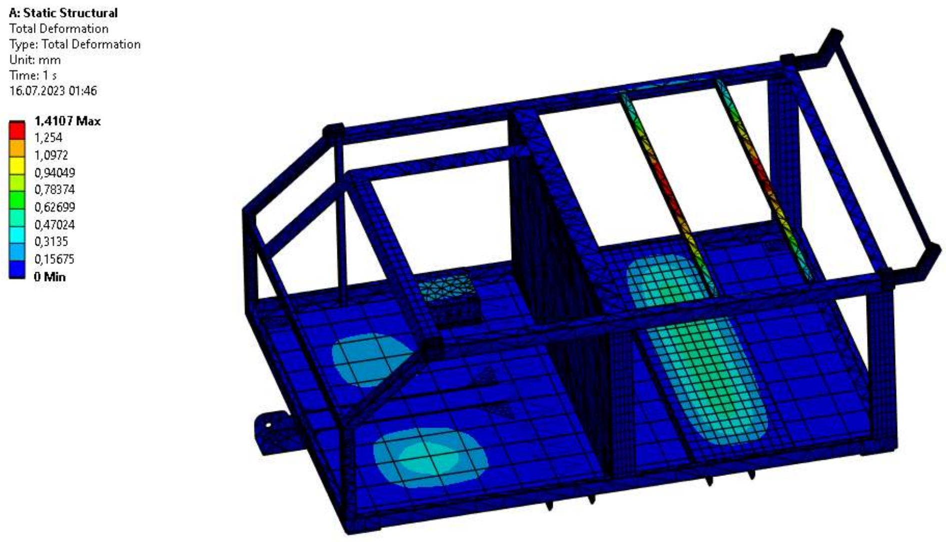

Figure 5.4 Deformation distribution obtained under the loading condition in the mobile FE-PCA unit

The maximum deformation amount of the current design under the loading condition has been measured as 1.41 mm. The observed stress values (von-Mises stress) of the current chassis under the defined boundary conditions and loading conditions are presented in Figure 5.5.

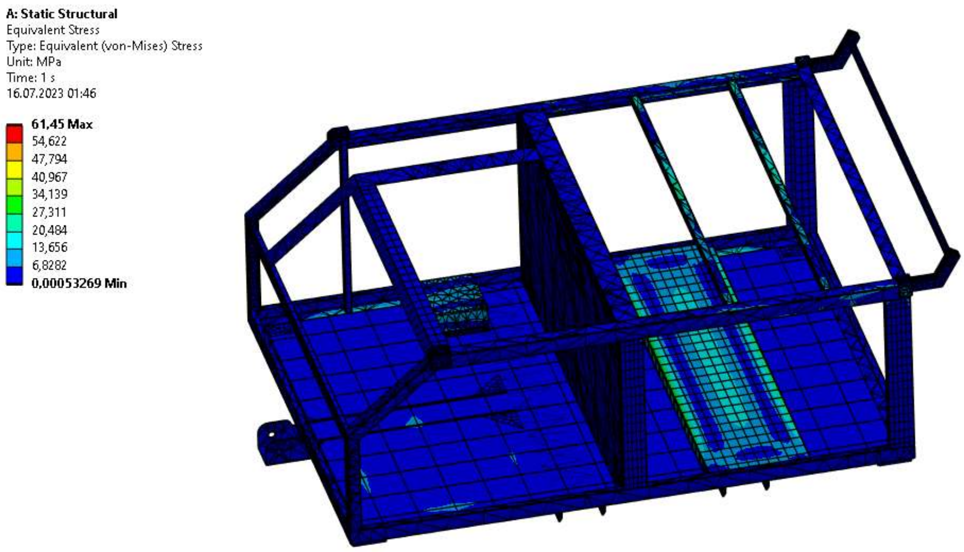

Figure 5.5 Stress distribution obtained under the loading condition in the mobile FE-PCA unit

The stress levels observed in Figure 5.5, generally indicate that the existing chassis is structurally safe, with localized and surface stresses observed only in specific loading points on the upper chassis and lower base plate. The stress level at critical points has been observed to be 61 MPa, which is within the yield strength limit of the S235JR material used, measured at 235 MPa and it has been observed to be in the plastic region.

Safety factor of the chassis, as determined by the load analysis, is provided in Figure 5.6. This value is found to be 3.8, indicating that the chassis is in a safe condition.

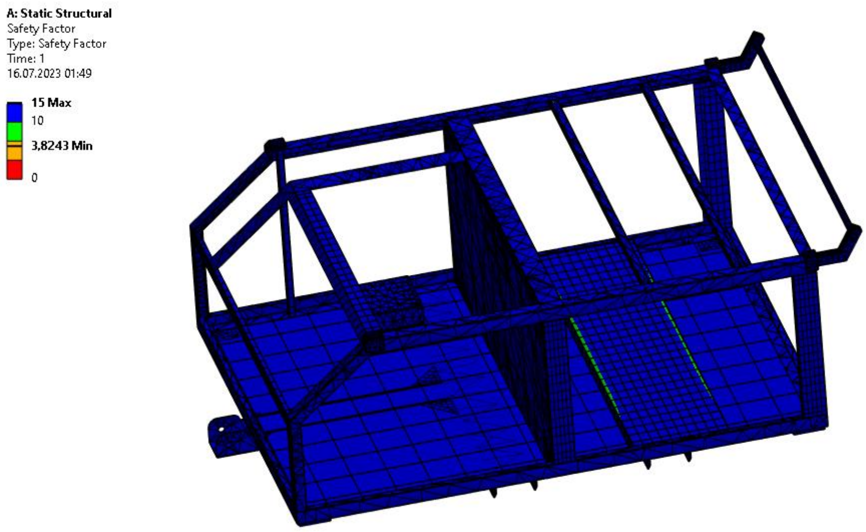

Figure 5.6 Safety factor obtained under the loading condition in the mobile FE-PCA unit

Considering that carrier vehicles will carry a load equal to the weight of the mobile FE-PCA unit, a tensile force equal to the weight of the unit has been applied to the unit's towing iron region. The resulting maximum deformation amount is 0.02 mm, as shown in Figure 5.7 and the von Mises stress is 21.8 MPa, as shown in Figure 5.8. According to the safety factor of 10.8, it is determined that there will be no issues in the towing iron region of the chassis.

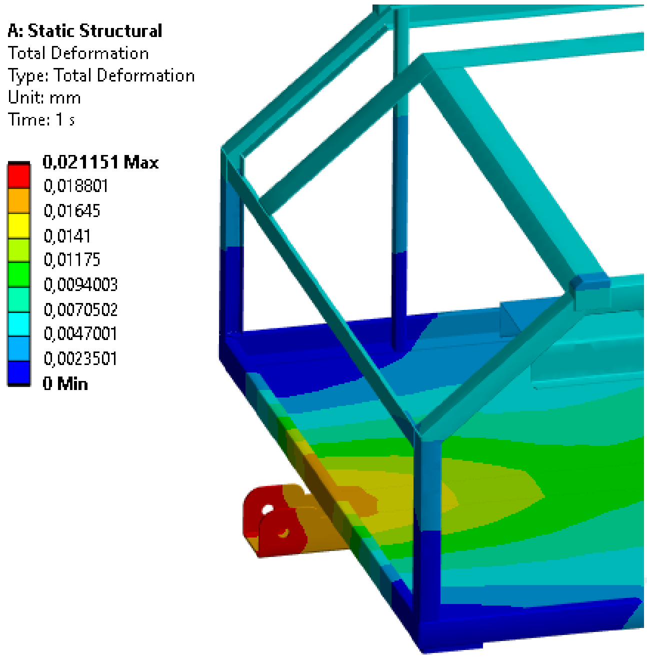

Figure 5.7 Maximum deformation amount in the tow bar region of the mobile Fe-PCA unit

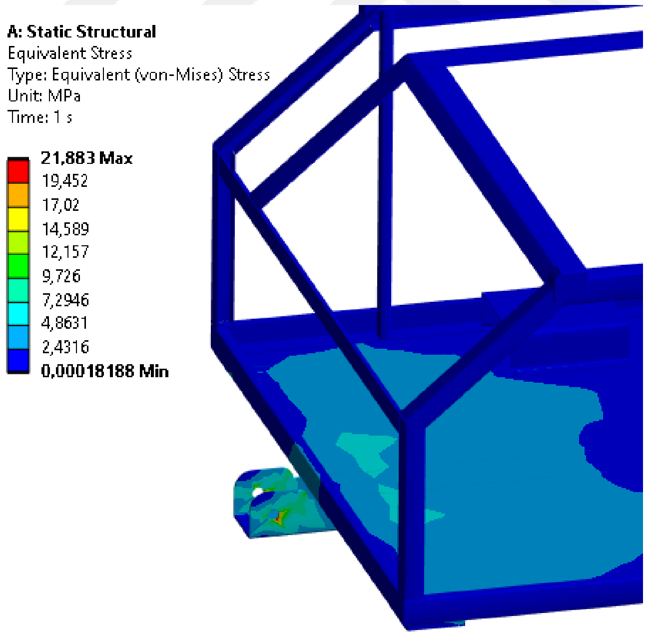

Figure 5.8 Von mises stresses of the tow bar region of the mobile FE-PCA unit

Based on all the analysis results and force definitions, it has been determined that there will be no permanent deformation in any region of the unit's chassis and thus, the structural safety of the mobile FE-PCA unit has been confirmed.

CHAPTER 6

CONCLUSION

The aim of the mobile FE-PCA unit, designed for maintenance and ground checks of an unmanned combat aerial vehicles (UCAV) prone to overheating tendencies in its electronic devices, is to mitigate the adverse effects of overheating and maintain optimum operating conditions effectively without the need for other resources within the UAV. This unit can efficiently cool or if necessary, heat the UCAV as required. The heating and cooling system will draw its energy from the central grid or generator available in the operating area.

By utilizing the unit in conjunction with a ground power unit (GPU) during ground tests and maintenance activities, there is no need to run the aircraft's engine. This results in fuel savings and ensures the safety of the technicians working on the aircraft. Consequently, the technicians can prepare the UCAV for flight, making it ready for operation.

The FE-PCA unit provides a continuously reliable operation with low maintenance requirements and a long service life. It offers a portable, economical, durable, and efficient solution that can be used in various environments and weather conditions. The system components are integrated onto a sturdy steel chassis, designed specifically to adapt to different climate conditions.Chassis is the main structural element that supports all the weights within the unit. Therefore, the material selection and chassis design are tailored to the usage area and purpose. In this thesis, a type of chassis composed of highly resistant L-bent parts is considered, allowing for easy shaping and convenient design modifications.

When selecting the material for the chassis, S235JR steel was chosen due to its welding capability, high strength structure, economical properties and easy and quick availability. For the unit covers, Aluminum 5754 material was preferred to avoid unnecessary weight while ensuring sufficient strength.

Portability of the unit allows for greater flexibility, enabling it to be easily towed to the desired location and provide service to various aircraft throughout the day. This flexibility helps in handling maintenance and equipment issues more efficiently and quickly. Additionally, it allows for rapid deployment in emergency situations.The added attachments make it suitable for air, land, or sea transportation.

Considering that fuel is one of the major costs for an aircraft, the FE-PCA unit and GPU help reduce fuel consumption, thereby lowering expenses and generating fewer emissions, which is more environmentally friendly. During the detailed design phase, the assembly sequence of components has been taken into account to ensure the most suitable design for manufacturing. If required, a design concept suitable for mass production has been developed.To protect the unit from environmental factors and prevent corrosion in vulnerable areas, appropriate coating and painting processes have been applied to enhance corrosion resistance. The design has been optimized to achieve energy efficiency, reduce emissions, consider environmental conditions, optimize space utilization, enhance operational efficiency and minimize costs.

This study provides a general overview of climate control systems and various PCA (Pre-Conditioned Air) units under the literature section. Subsequently, it offers a brief introduction to the components used in the refrigerant flow system and then the component selections and calculations are made.

As a result of the system design, mechanical design, and analysis, a new generation mobile PCA unit with a cooling capacity of 21.6 KW has been developed. Based on all the analysis results and force definitions, it has been determined that there will be no permanent deformation in any part of the unit's chassis, ensuring the structural safety of the mobile FE-PCA unit. Thanks to the designed unit, unmanned combat aerial vehicles will be able to perform critical attacks, coordination and intelligence reconnaissance reliably..

For future work, the placement of system components in the mobile FE-PCA unit can be further minimized, allowing for a reduction in the unit's dimensions. This approach would result in using fewer parts during the design phase and, consequently, creating a smaller and lighter device.

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