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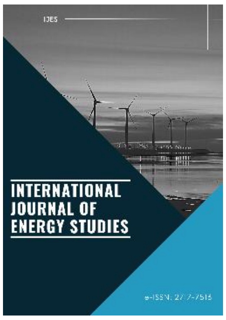

Research Article
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Wall-mounted split air conditioner fault diagnosis and service procedures training set

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Highlights

- Electrical fault detection in wall-mounted split air conditioners can be performed through simulated malfunction scenarios.
- Changes observed in the unit are analyzed to clearly identify fault causes and present possible solutions.
- Learners gain the capability to produce informed and effective solutions to real fault scenarios.

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ABSTRACT

Wall-mounted split air conditioners are the most widely used heat pump air conditioner type in Turkey. They are used extensively in living and working environments for cooling in the summer and heating in the winter. This widespread use has significantly increased the need for trained, informed, and analytically minded technical personnel capable of pinpointing, fault diagnosis, and properly servicing devices. This training set, produced for educational purposes, aims to comprehensively teach the operating principles, service procedures, electrical fault detection, temperature and pressure changes, and fault diagnosis methods of wall-mounted split air conditioners. All manufacturing processes are detailed, and circuit diagrams are drawn, explaining the operating principle of the set in a manner suitable for use in vocational and technical schools. This study examines the electrical fault detection, service procedures, and changes in the device resulting from artificial faults in wall-mounted split air conditioners using the developed training set. The causes of these faults and their possible solutions are explained.

Keywords: Split-type air conditioner, Fault detection, Service operations, Training set

1. INTRODUCTION

Wall-mounted split air conditioners, the most commonly used type of air conditioners in Turkey, regulate indoor temperature regardless of fluctuations in outdoor conditions, dehumidify the environment in cooling mode, provide air movement within the space, clean the air using filters, and, in some models, renew the air using fresh air intakes [1,2]. In this way, they ensure that living and working environments achieve the desired comfort or production conditions. In recent years, rapidly changing climate conditions have made air conditioning mandatory in many regions of Turkey, especially during the summer months. Properly identifying and resolving air conditioner malfunctions that may occur during extremely hot summer days or extremely cold winter days is crucial. Therefore, the need for competent technical personnel who can accurately diagnose and quickly resolve any detected malfunctions is increasing in the split air conditioning sector. Proper response to malfunctions that occur during extreme or unexpected weather conditions is particularly critical. The developed training set operates based on the vapor-compression refrigeration cycle, which is widely used today. The air conditioner on this heat pump set consists of two main parts that transfer heat. These are an indoor unit that exchanges heat with the indoor environment and an outdoor unit that exchanges heat with the outdoor environment. The outdoor unit contains the compressor, condenser, four-way valve, two fluid control devices (capillary tubes), the outdoor fan motor, check valve, and accumulator. The indoor unit contains the evaporator, outdoor fan motor, damper (flap) motor, power and control board [3]. These two units are interconnected by copper pipes for refrigerant exchange, wiring for signal exchange, and a drain hose for condensed water transfer to the outdoor environment. The evaporator on the indoor unit of the training set and the compressor, condenser, and capillary tubes within the outdoor unit are sealed with copper pipe unions. The system was vacuumed and the ideal amount of refrigerant was charged. Heating and cooling in air conditioning systems are achieved through a refrigerant circulation system whose primary function is heat transfer. As the refrigerant evaporates under low pressure and at a temperature below the ambient temperature, it absorbs heat from the desired space. Then, under high pressure and at a temperature above the ambient temperature, it condenses and transfers this absorbed heat to the outside environment. Two fans, one indoor and one outdoor, are used in the system to accelerate heat transfer to and/or from the indoor and outdoor refrigerants. Dual capillary tubes and a check valve are incorporated into the circuit to reduce the gas pressure in the system. When the refrigerant is sprayed from the small-cross-section capillary tube to a large-cross-section area, the pressure drops. As the refrigerant, which has a temperature lower than the ambient temperature, evaporates, it absorbs the heat from the surrounding environment, cooling the environment. If the evaporation process occurs within the outdoor unit by energizing the four-way valve coil, heat transfer occurs from the outdoor environment to the refrigerant. This heat is transported to the indoor unit via the compressor. As the refrigerant condenses on the indoor unit coils, the heat released to the indoor environment heats the surroundings. In cooling mode, a capillary tube and check valve are used in the outdoor unit to reduce pressure, while in heating mode, flow occurs through two capillary tubes in the outdoor unit. In the wall-mounted split air conditioner fault diagnosis and service procedures training set, the software within the microcontroller recognizes commands sent by the user via the remote control. This software operates an automatic control system that sends sequential commands to the electrical components in the system, enabling the air conditioner to operate. This automatic control system controls various components operating at 12 Volt DC and 220 Volt AC [4,5]. The system uses a program to sequentially start and stop key components such as the compressor, indoor unit fan motor, outdoor unit fan motor, and the four-way valve, which operates in heating mode [6]. The training set contains two thermistors that detect ambient temperature and gas temperature. The program converts the resistance changes in these thermistors into temperature information, directs the necessary elements, and manages the system [7].

The increasing sophistication of air conditioning systems, driven by technological advancements, is increasing the need for competent and well-equipped technical personnel in fault diagnosis, maintenance, and repair processes. In this regard, the use of applied teaching materials in vocational training is crucial for reinforcing theoretical knowledge with concrete applications and equipping students with practical skills. This fault diagnosis and service training set, specifically designed for wall-mounted split air conditioning systems, aims to provide students with hands-on experience under real-world system conditions. The training set allows for the diagnosis of potential faults in control, power, and sensor circuits, the implementation of service procedures, and the observation of the effects of excess or insufficient refrigerant on system performance. This set, which is intended to be widely used in vocational and technical education institutions in the field of air conditioning, is expected to make significant contributions to the training of qualified personnel specialized in individual air conditioning systems.

2. METHOD

In this study, the features of the training set developed for the air conditioning, cooling and heating field and the applications performed on it are explained.

2.1. Experimental Model

The system's indoor and outdoor units are mounted on a welded metal base. The air conditioner's power, control, and sensor board are located at the bottom of the indoor unit. This system, first developed and introduced to the industry at the Adana Vocational School Air Conditioning and Refrigeration Laboratories in Turkey, includes an air conditioning compressor and two separate electricity meters to monitor the entire system's electricity consumption. To monitor the compressor's real-time energy consumption, a datalogger was added to the system, allowing it to read voltage, current, and power factor (Cosφ) values on the compressor line. Furthermore, a power meter (wattmeter) was connected to the system's power input, allowing for instantaneous system power consumption monitoring. Two refrigerant tanks, controlled by solenoid valves, were added to the system to facilitate service operations and monitor the effects of excess or insufficient refrigerant on the system. Figure 1 displays the schematic of the training set, Table 1 provides the air conditioning unit technical specs, and Table 2 details the measurement equipment.

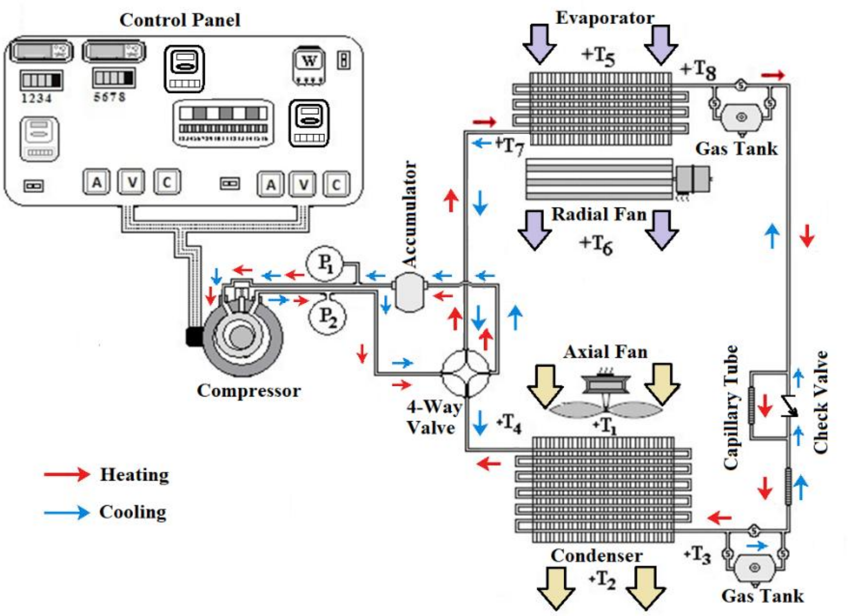

Figure 1. Split air conditioner fault detection and service operations training set principle diagram

Table 1. Technical specifications of the split air conditioner used in the split air conditioner fault detection and service operations training set

Technical specifications	*Cooling*	*Heating*
Capacity	9000 Btu/h -2639 W	9700 Btu/h - 2844 W
Rated power	900 W	870 W
Rated current	3,9 A	3,8 A

Voltage	220-240 Volt, 50 Hz	220-240 Volt, 50 Hz
Refrigerant amount	0,71 kg R22	0,71 kg R22

Table 2. Measurement devices and their features used in the split air conditioner fault detection and service operations training set

Measured value	*Measuring device*	*Pieces*	*Measuring range*	*Margin of error*
Temperature (ºC)	Digital thermometer	2	-50/150 ºC	±%1
Suction-discharge line pressure (Bar)	Bourdon-type oil pressure gauge	2	-1/35 Bar	±%1,6
Compressor power (watt)	Wattmeter	1	0/6000	±%1,0
System and compressor voltage (Volt)	Digital voltmeter	2	250 VAC	±%1,0
System and comp. current (Amp)	Digital ammeter	2	1 ila 120A	%1(±2)
System and comp. power factor (%)	Digital cosφ meter	2	0-1ind, kap.	± 1%
Temperature detection (ºC)	Probe	8	-60,150 °C	± 1%
Electricity consumption (kWh)	Meter kwatt-hours (kWh)	2	A.A.10(40)	±%2

In cooling mode, the temperature and pressure sensor values of the training set are shown in Table 3. In heating mode, the condenser functions as the evaporator, and the evaporator functions as the condenser [8]. Under changing operating conditions, the condenser and evaporator refrigerant inlet and outlet sensor values are read in reverse, and there is no change in suction and discharge pressures.

Table 3. Measurement points used in the split air conditioner fault detection and service operations training set

T1 Condenser air inlet	T5 Evaporator air inlet
T2 Condenser air outlet	T6 Evaporator air outlet
T3 Condenser gas inlet	T7 Evaporator gas inlet
T4 Condenser gas outlet	T8 Evaporator gas outlet
P1 Suction pressure	P2 Compression pressure

2.2. Operation of the Training Set in Cooling and Heating Mode

Effectively diagnosing and repairing a system depends primarily on a thorough understanding of the system's operating principle and the interconnected components. In this training set, when the cooling mode is activated via remote control, the system's initial operation is initiated by the flap motor being turned on. In this mode, the four-way valve remains in the cooling position, meaning the valve coil is not energized. During the cooling process, the refrigerant, compressed by the compressor, is sent to the condenser (outdoor unit) as superheated vapor at high pressure and temperature. Condensing within the condenser, the refrigerant releases its heat energy to the outside environment and transitions to the liquid phase. This liquid fluid experiences a pressure drop as it passes through the capillary tube and the check valve. Additional pressure losses also occur in the connecting pipes between the indoor and outdoor units. The liquid refrigerant, which has decreased pressure and has partially expanded into a boiling state (flash), is directed to the lower and upper evaporator surfaces via distribution pipes in the indoor unit. Here, the refrigerant, which has the opportunity to evaporate over a large surface area, converts to vapor while absorbing heat from the environment. Thus, the heat absorbed from the indoor environment is loaded into the refrigerant. At the evaporator outlet, the fully saturated vapor refrigerant is reabsorbed by the compressor. During this process, it absorbs some heat from the compressor windings, turning into superheated vapor, and the cycle restarts. As a result of this thermodynamic cycle, the heat absorbed from the environment during evaporation in the indoor unit is transferred to the environment during condensation in the outdoor unit. Thus, effective cooling of the environment is ensured. In Figure 1, the operating scheme of the split air conditioner fault detection and service operations training set in cooling mode is shown with blue arrows. In the training set when the heating mode is activated, the system's initial movement begins with the flap motor moving half a revolution. This action activates the compressor in the outdoor unit, the outdoor unit fan motor, and the four-way valve. If the ambient temperature is below the user-set value, the indoor unit fan motor starts operating when the indoor unit temperature reaches the software-defined value, along with the temperature signal from the pipe sensor. In this mode, the four-way valve is active, ensuring that the refrigerant in the system is directed to the indoor unit. During the heating process, the refrigerant, directed by the four-way valve, is delivered from the compressor to the indoor unit as superheated vapor at high pressure and temperature. The refrigerant, condensing in the indoor unit, transfers its heat to the environment, warming the space. The refrigerant traveling through the pipes between the indoor and outdoor units experiences some pressure loss during this transition. Because the check valve prevents the refrigerant from passing through this line, it is unable to flow through the first and second capillary tubes. The refrigerant, which experiences a further pressure drop as it passes through the capillary tubes, vaporizes in the outdoor unit and, absorbing heat from the surroundings, transforms into vapor. The vaporized refrigerant passes through the four-way valve and reaches the compressor. During this time, it absorbs some heat from the compressor windings and turns into superheated steam, thus becoming ready for a new cycle. In heating mode, the refrigerant, which absorbs heat from the environment during evaporation in the outdoor unit, condenses in the indoor unit and transfers this heat to the living space. Thanks to this thermodynamic cycle, the environment is heated. In Figure 1, in the heating mode is shown with red arrows.

2.3. Service Operations Applications

In order to achieve the unit heating and cooling achieved in heat pumps with the least amount of energy consumption, the optimum amount of gas determined by each air conditioner manufacturer in their research and development laboratories must be kept in the system [9]. Excess or insufficient refrigerant reduces cooling/heating capacity and increases energy consumption. This reduces the unit's efficiency. Electrical work damages the compressor and its windings, the main component. The refrigerant amount affects the temperature and pressure balance within the system [10,11]. Charging refrigerant according to the full catalogue value is essential for the healthy, efficient and long-lasting operation of the air conditioning system. If extra piping is added, additional refrigerant must be calculated separately and added to the system according to the manufacturer's tables. To provide training on over and under refrigerant loading and refrigerant collection in the training set, two gas tanks were installed in the system and controlled by solenoid valves. Figure 2 shows the equipment required for refrigerant charging. When an R22 split air conditioner is deficient in refrigerant (insufficient refrigerant), some significant deviations occur in the system's technical specifications and behavior. These deviations are shown graphically in Figure 3. Usually, at normal temperatures, a manometer reading of 60 psi is required for an air conditioner running on R22 refrigerant in cooling mode. Under refrigerant charge will result in low pressure. Due to sudden evaporation in the indoor unit, icing, water, and snow may occur. The pipe sensor temperature drops. The compressor current draw decreases. Cooling performance decreases. Insufficient refrigerant from the indoor unit (evaporator) to absorb the heat of the compressor windings causes the compressor windings to overheat, resulting in mechanical wear and tear during high-temperature operation and rapid deterioration of the compressor oil. This can lead to frequent thermal trips and subsequent failures in the compressor windings. Excessive refrigerant charge strains the compressor, creating high pressure in the system. The compressor current draw increases. Liquid can flow into the compressor. The return line may become clogged or snowy. The compressor is overloaded and tripped by the overcurrent protection circuit. Frequent repetition of this can damage the compressor windings. Since the refrigerant cannot evaporate sufficiently in the indoor unit, the cooling capacity of the air conditioner decreases. Proper refrigerant refilling is crucial for the efficient and trouble-free operation of your split air conditioner. Prior to this, it is essential to vacuum the system and completely remove all air and moisture from the pipes and the air conditioner itself. To vacuum the indoor and outdoor unit connection pipes, the service end of the charging hose is connected to the vacuum pump, as shown in Figure 2. Then, the low-pressure hose of the manifold is connected to the three-way service valve port of the outdoor unit. The low-pressure valve of the manifold is opened and the pump is started. The vacuum pump's evacuation time depends on the length of the pipes and the pump's capacity. The times specified in the catalogs must be adhered to in this regard. Generally, a 20-minute vacuum is recommended for air conditioners rated between 7.000 and 18.000 BTU/h, and a 40-minute vacuum is recommended for air conditioners rated between 18.000 and 28.000 BTU/h. Vacuuming should be performed at -20 psi for the above specified time using an 8.5 m3/h vacuum pump. Once the desired vacuum is achieved, the manifold low-pressure valve is closed and the vacuum pump is stopped. If the pressure gauge is checked for 5-10 minutes, if the pressure gauge needle rises, there is a leak in the system. The leak is located and repaired, and the vacuum is reapplied [12].

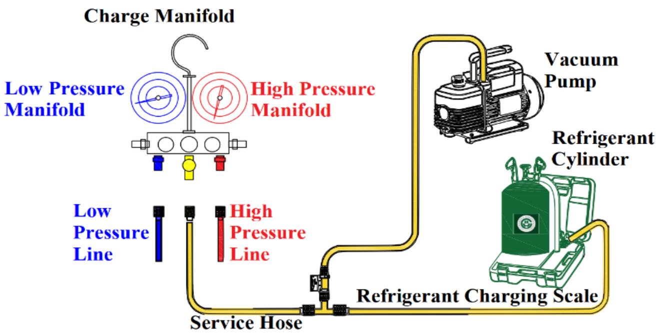

Figure 2. Service equipment used in the training set

Then, the correct type of refrigerant to be used in the system is determined and the required amount is precisely measured with a digital refrigerant charging scale. Refrigerant is slowly introduced into the system, usually from the low-pressure line, through the manifold gauge. During this time, the amount specified on the system label or installation manual must be taken into account and overfilling or underfilling must be avoided. Once the process is completed, the connections are disconnected, the sealing is checked with soapy water or an electronic detector, and the device is operated to observe its performance. All these steps are critical to the longevity and efficient operation of the wall-mounted split air conditioner. Figure 3 shows the graphs illustrating the effects of excessive refrigerant charging applied via refrigerant tanks in the training set.

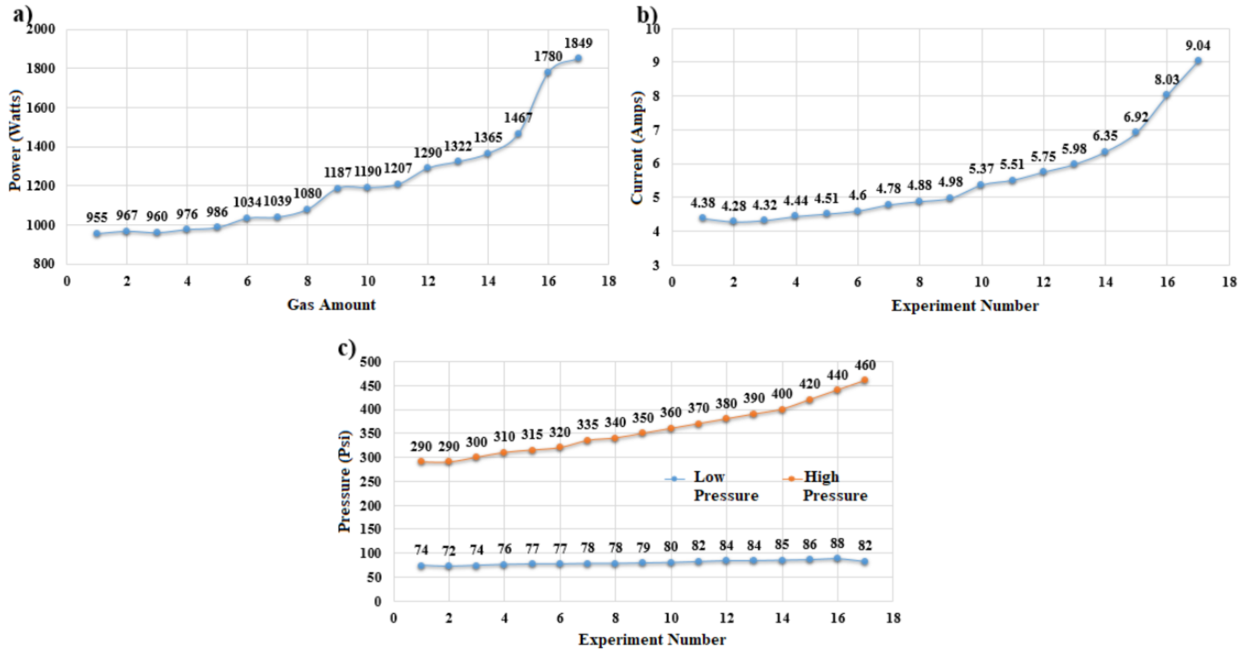

Figure 3. Effects of excess gas charge applied through refrigerant tanks

In the overcharge refrigerant application, the system was operated normally, brought to equilibrium, and then the temperature, pressure, and electrical energy consumed were measured, and the following changes were observed. With the gradual increase in the amount of refrigerant added to the system, an increase in the energy consumed by the system was observed. With the gradual increase in the overcharged refrigerant charge, the system's power output increased from 955 watts to 1849 watts (Figure 3a). The increase in the refrigerant amount will cause compressor strain due to the increased pressure in the system. This strain is clearly evident in the compressor noise. This will cause the system to consume more power than normal. When the refrigerant amount in the system was increased by 10 grams, the flow rate also increased gradually. Increases were also observed in the system's suction and discharge pressures. The low-pressure value increased from 74 psi to 82 psi, and the high-pressure value increased from 290 psi to 460 psi. In the incomplete refrigerant charging application, 710 g of refrigerant, which is the catalog value of the split air conditioner used in the training set, was charged to the system after vacuuming. The gas charge was made with a scale, then the refrigerant was gradually reduced by 10 grams and the system responses were monitored. The graphs in Figure 4 show that the overall system power draw decreased from 811 watts to 475 watts (Figure 4a), while the low pressure in the system decreased from 75 psi to 9 psi and the high pressure from 260 psi to 140 psi (Figure 4b). The evaporator gas inlet temperature decreased from 15ºC to 22ºC, and the evaporator gas outlet temperature decreased from 16ºC to -10ºC (Figure 4c).

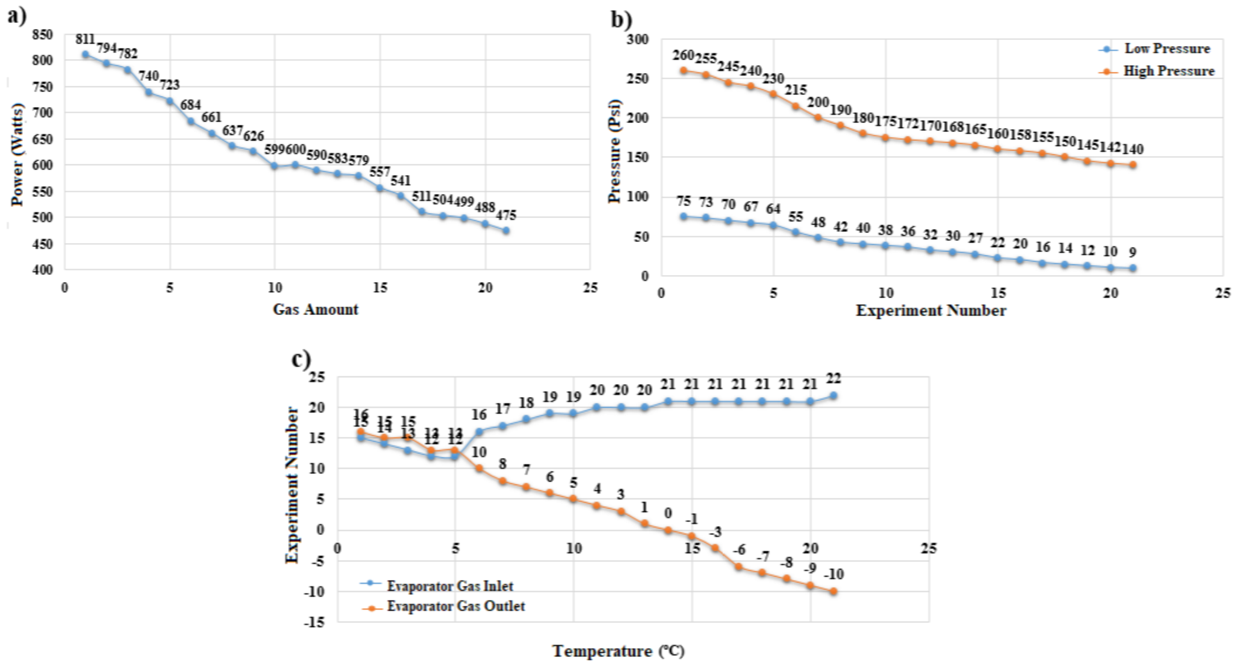

Figure 4. Effects of low gas charge applied through gas tanks

2.4. Electrical Circuit and Operation of the Training Set

In the electrical circuit shown in Figure 5, when the training set is activated via a wattmeter connected to the system input, the instantaneous power consumption of the entire system can be monitored on the wattmeter's digital display. The wattmeter output is connected to the phase, neutral and ground lines of the electricity meter installed in the system in order to see the amount of energy consumed by the entire system. A 16 ampere W-automat is mounted on the meter output phase line for protection in case of overcurrent and short circuit in the circuit. The incoming phase is connected to the system directly in front of the compressor relay. Switch 1 is located on the compressor relay power circuit phase line to cut off the power supply to the compressor relay power circuit. It passes through the neutral indoor unit terminal and is connected to the main board via the socket. Grounding is secured to the evaporator plate with a screw. The phase is carried to the main board via a six-pin socket. Compressor relay connection point Phase 250 V–2 A is passed through the fuse. The function of the glass fuse is to protect the circuit board against any malfunction that may occur. Before the glass fuse output connects to the four-way valve relay, switch number 2 is installed to interrupt the power supply to the four-way valve relay's power circuit. This output connects to the signal terminal to activate the phase and valve coil on the outdoor unit. Switch number 3 is installed to interrupt the power supply to the fan relay's power circuit on the other input of the phase. At the switch output, the phase connects to the other terminal of the signal terminal to activate the fan. The relays on the board are electromechanical switches that energize the coil connected to the 12-volt DC voltage coming from the microprocessor, seal the contacts, and transmit 220-volt AC energy to the indoor unit connection terminal through the contacts, controlling high-power circuits with low current. When the coil control circuit is energized, a magnetic field is created, and the contacts of the power circuit close. The element to which it is connected works. In other words, if the microprocessor does not send power to the coil, the receiver to which it is connected stops operating.

The other input of the distributed phase line passes through the triac. Indoor unit fan motor fault switch No. 4 is located before the socket connection. The switch output phase is connected to the indoor unit fan motor. The indoor unit fan motor neutral cable is connected to the neutral socket. Switch number 5 was placed on the permanent circuit capacitor line in the circuit, thus disabling the fan capacitor. The switch output completes the phase circuit via the indoor unit fan capacitor. The microprocessor is the element that converts user commands into electrical signals and operates the air conditioner components sequentially, thanks to the software installed within. The microprocessor's 12 V DC power switch output on the control board completes the circuit from the microprocessor's power supply terminal. The control board contains two NTC temperature thermistors, which transmit ambient and gas temperature to the microprocessor as a varying resistance. The resistance of NTC thermistors will decrease as they heat and increase as they cool. Due to their nature, temperature-resistance tables are non-linear. The ambient temperature sensor is covered with polyester. The sensor is mounted on the indoor unit coils. Fault switch No. 10 is located on the sensor's power input cable. The circuit is completed at the switch output, and the sensor transmits ambient temperature changes to the microprocessor as variations in resistance. Likewise, fault switch no. 7 is placed on the input cable of the copper pipe temperature sensor placed on its socket in the copper pipe to detect the device temperature. The circuit is completed at the switch output, with the sensor transmitting the gas temperature as a resistance change to the microprocessor. The damper swing motor, known in the market as a step or flap motor, is located at the air outlet of the split air conditioner indoor unit and ensures that the blown air is distributed homogeneously throughout the room. Fault switch No. 8 is placed on the input cable of this motor, which operates at 12 V DC. The circuit is completed at the switch output, and the stepper motor performs the air distribution movement based on the command it receives from the microprocessor. In air conditioners, the receiver board detects infrared (IR) signals from the remote control and transmits them to the control board. This allows the air conditioner to operate at the set temperature and features according to the commands sent by the user via the remote control.

Fault switch No. 9 is placed between the output cable of the receiver board and the power socket. The circuit is completed via the electronic circuit on the switch output receiver card. Figure 5 shows the electrical circuit diagram of the indoor unit of the training set and the locations of the fault switches.

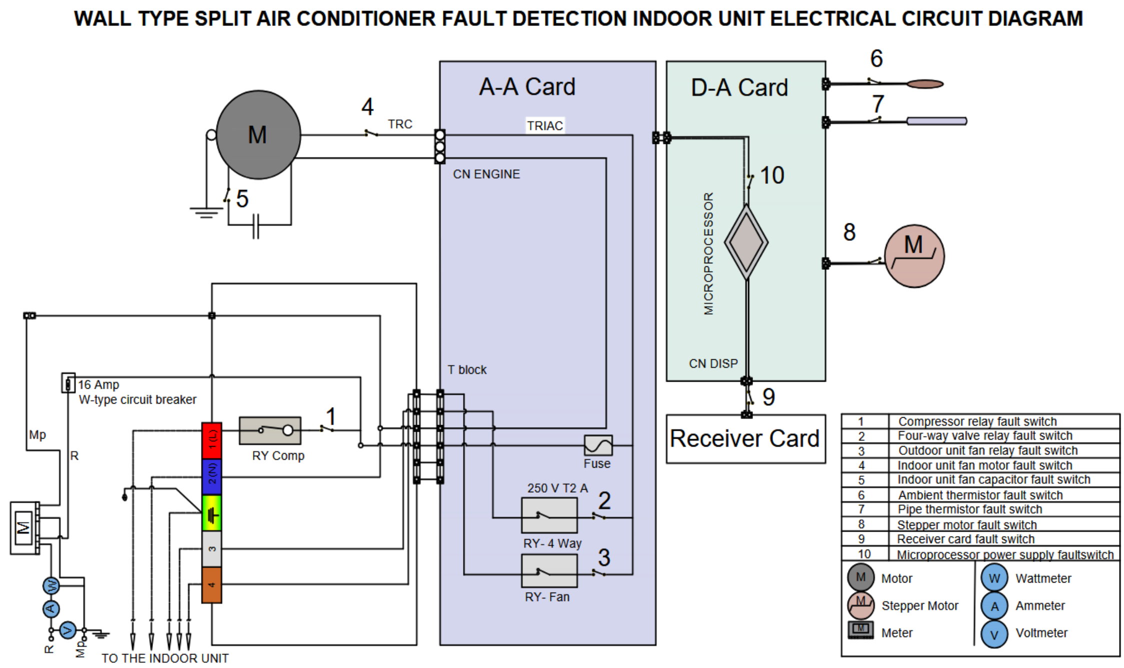

Figure 5. Electrical circuit diagram of the indoor unit of the training set and locations of fault switches

Figure 6 shows the outdoor unit electrical circuit diagram and the locations of the fault switches. A 5x1.5 mm^2 TTR (multi-wire thermoplastic insulated) cable is run from the indoor unit of the training set to the outdoor unit and connected to the outdoor unit terminal. The indoor unit compressor relay is connected to a mechanical electric meter to monitor the compressor's energy consumption from the power circuit. An ammeter is connected to measure the compressor's output phase current, a cosφ meter is connected to measure the power factor, and a voltmeter is connected between the compressor phase input and neutral lines. This allows for the calculation of the compressor's instantaneous power values. A No. 11 compressor thermal fault button has been installed on the compressor phase line at the common terminal of the thermal protector. The button output connects to the thermal switch and, through the thermal switch, to the compressor's common terminal, completing its circuit via the common terminal of the main winding and capacitor. This button monitors the system's behavior in the event of thermal faults. Compressor fault button number 12 is placed at the output of the thermal switch, without any input to the compressor's common terminal. This button output completes its circuit through the common terminal of the compressor and the common terminal of the main winding capacitor (C). The auxiliary winding of the compressor completes its circuit at the end of the capacitor (HERM). This capacitor will remain permanently in the circuit and will increase the rotation torque by creating a ninety-degree phase difference between the main and auxiliary windings, and the compressor will operate. Compressor capacitor fault button no. 13 is placed between the auxiliary winding and the HERM end of the capacitor. The most common fault in an on/off air conditioner is capacitor failure. Therefore, it is important to observe the behavior of the system when this switch breaks the circuit. The four-way valve coil fault button number 14 is placed on the valve coil output line. The button output completes its circuit via the common terminal of the capacitor. The phase coming from the fan motor relay power circuit on the main board is connected to the fan motor fault switch no. 15 before entering the common end of the fan motor main winding and the fan motor. The switch output completes the circuit through the common terminal of the fan motor main winding and the capacitor. Fan motor capacitor fault switch No. 16 is placed on the auxiliary winding capacitor fan connection. At the switch output, the circuit completes the circuit through the fan terminal of the capacitor. If the switch is closed, the fan motor operates. A 35+1.5µF capacitor is used for the compressor and outdoor unit fan motor.

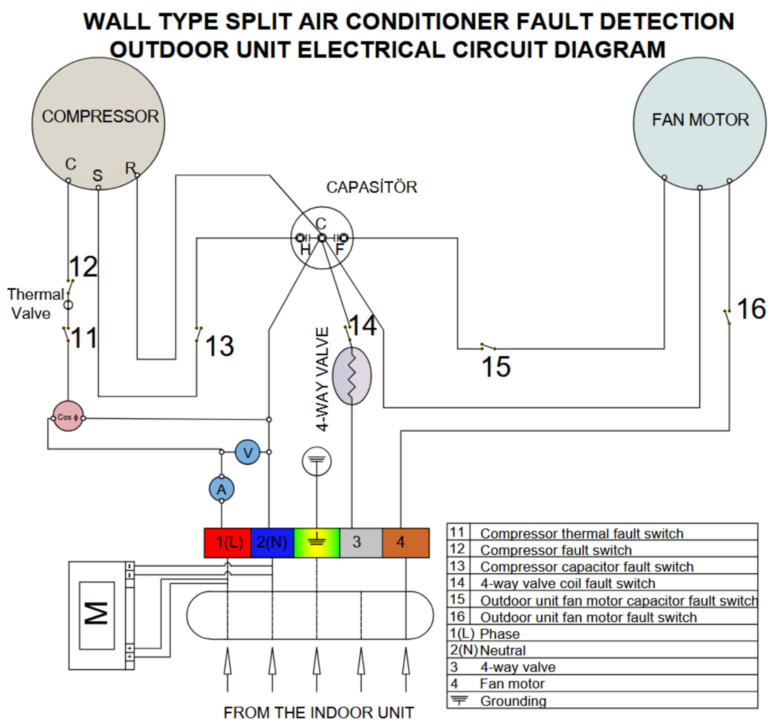

Figure 6. Training set outdoor unit electrical circuit diagram and fault switches

3. RESULTS and DISCUSSION

This section includes the findings obtained from the applications performed on the split air conditioner fault test set. These findings include not only measurement results but also experimental outputs that allow users to observe the progression of different types of faults. In Table 4, the designed fault switch numbers and the electrical faults they create are given in tabular form.

Table 4. Fault key numbers and the electrical faults they cause

No	*Fault*	*No*	*Fault*
1	Indoor unit fan motor fault	**9**	Compressor thermal fault
2	Indoor unit fan capacitor fault	**10**	Four-way valve relay fault
3	Room (ambient) sensor fault	**11**	Four-way valve solenoid coil fault
4	Pipe sensor fault	**12**	Display power supply fault
5	Compressor fault	**13**	Display sensor fault
6	Compressor run capacitor fault	**14**	Microprocessor power supply fault
7	Outdoor unit fan motor fault	**15**	Damper (flap) motor fault
8	Outdoor unit fan motor capacitor fault	**16**	Outdoor unit fan relay fault

The air conditioner is not working; a fault can be diagnosed based on the electrical and mechanical symptoms occurring in the system. In this case, the phase-neutral voltage at the input and output terminals of the W-type circuit breaker is checked with a multimeter to verify whether there is 230V input to the unit. If the system is not receiving any power, the fuse on the building panel to which the air conditioner is connected may have blown. If the W-type circuit breaker input is energized but the output is not, the W-type circuit breaker may be faulty. In this case, the student or technician candidate also begins to receive training on the use of a multimeter and a test pen. Alternatively, if there is voltage, this time the phase input and output of the air conditioner's glass fuse is checked with a control pen or multimeter. If there is no power at the output, the glass fuse may have blown. This training set includes a 250 V, 2 ampere glass fuse, which is an element that protects the air conditioning board circuits against overcurrent. This fuse can often blow due to reasons such as overcurrent or short circuits [13]. The cause of the blown fuse should be determined and replaced with a new one of the appropriate amperage. A temporary solution, such as wrapping wire, should never be employed. If there is energy at the fuse output, the varistor is checked at this time. The varistor protects the control circuit against sudden high voltages; its resistance decreases as the voltage increases and protects the circuit by grounding the excess current [14]. In the event of an overvoltage, it acts like a short circuit and self-destructs. The faulty varistor is visually inspected (shape change, burn marks) to determine the fault and replace it with a new one with the same features. Because electronic boards operate on direct current (DC) [3], when a fault is detected on the board, the necessary checks must be performed carefully. The transformer powers the electronic board by reducing 230V alternating current (AC) and converting it to DC using a rectifier circuit. 230V AC is converted to 12V DC by a transformer and rectifier circuit. This low voltage obtained feeds the relay coil control circuits, ambient and pipe sensors, LED indicators in the system, sensor and control card circuits. If 12 V DC power cannot be measured in the power supply to these elements, the transformer is faulty. Transformer failure usually occurs as a result of a short circuit or overheating [15]. The primary winding of the transformer is measured by checking the resistance value with a multimeter on the card. To detect a secondary winding fault, the transformer must be removed from the board. If a fault is detected in the transformer at the end of the measurement, the transformer is replaced with a new one. When the microprocessor supply fault switch on the training set is placed in the fault position, it can be observed that the air conditioning system does not work. Because there is software installed in the microprocessor. Thanks to this software, the microprocessor converts the commands coming from the user into electrical signals and sends output signals to the air conditioning control elements (compressor, fan, valve, etc.) in the specified order and within the specified time. When the appropriate DC voltage cannot be provided to the microprocessor (power input) or when there is an irregularity in system operation, the transformer 12V supply circuit connections and output values should be checked. If the problem is not detected in other elements, there may be a software or microprocessor failure. In this case, the card must be replaced completely [16]. A compressor thermal switch is an electrical protection element that protects the compressor covers of cooler-mounted split air conditioning systems against overcurrent and overheating. When these conditions occur, it interrupts the circuit, preventing insulation damage and compressor burnout. The training set includes a switch at the thermal switch input to allow monitoring of these protection options. This process allows for a more controlled and safer investigation of potential system malfunctions. The bi-metal material in its thermal structure is formed by combining two metals with different expansion coefficients. When the compressor overheats during operation, these two metals expand at different rates. With further expansion of the outer metal, the bimetal contact opens and the energy input to the compressor is cut off. In this way, damage that may be caused by excessive current draw is prevented. When the compressor cools, the bimetallic contact returns to its original shape, the contact closes, and the compressor restarts. This mechanism provides thermal protection for the compressor, ensuring longer life and safer system operation. If the air conditioning compressor in the training set does not work at all, if the compressor does not start even though the outdoor unit fan is running, or if the compressor stops working after a while, the fault may be in the thermal circuit. Damage such as burning, melting, or breakage may be found in the cable connections. The cables should first be visually inspected. If there is no physical damage, the compressor thermostat should be checked for malfunction by performing a continuity test with a multimeter or by observing whether it operates again after the system has cooled down. In the market, the thermal switch is often disabled for testing purposes. If the compressor activates, the thermal switch is considered faulty. If the thermal is faulty, the reason may be that the compressor is working at overload (gas may be insufficient/excessive), the condenser fan is not able to release heat from the system due to failure, low voltage or jamming. As a solution, if it is a thermal fault, it should be replaced with the same type of spare part and the gas pressure of the system should be checked. The compressor current and operating voltage should be tested. Compressor thermal failure causes gas flow to stop. The cause of the fault may not be solely thermal. Therefore, by performing all system checks in sequence, the thermal switch can be identified as the fault. In split air conditioners, when the solenoid coil on the four-way valve is energized by the user, the device is switched to heating mode.In other words, the piston movement inside the four-way valve directs the high pressure and temperature refrigerant at the compressor outlet to the indoor unit, allowing the indoor unit to heat the environment via the fan. In cooling mode, this coil is de-energized. If the air conditioner does not heat, it may be considered that the four-way valve coil is faulty. First, a visual inspection is performed to see if the valve coil is loose or dislodged. The coil sheath is checked for burns, melting, or discoloration. The resistance of the coil winding is tested with a multimeter. The coil ends are connected to the multimeter in the ohm (Ω) range. A resistance reading should be within the catalog value. If the reading is ∞ (infinity), there is a break in the coil. If the reading is 0 Ω or lower than normal, there is a short circuit in the coil winding. The coil on the training set is energized with 230 V AC. In heating mode, it should be checked whether 230 V AC voltage is reaching the coil. If the supply voltage is not available, the four-way valve relay is controlled. The four-way valve relay consists of a combination of power and control elements. The control element is the relay coil, and the current passing through it is a very small, weak current, sufficient to create the magnetic field necessary to move the contacts. Power elements are the relay's contacts, which conduct electrical energy and are opened and closed via the coil. All electrical energy supplying the circuit passes through the contacts. The relay coil can be checked by measuring resistance or by applying operating voltage to the relay power supply terminals. The coil terminal can be checked on the circuit board. To obtain more accurate results in diagnosing faults at the contact terminals, the relay should be disconnected from the electronic circuit board. Overcurrent can cause burns or oxidation at the relay contact terminals.

In this case, the relay cannot function. The compressor relay and outdoor unit fan relay are also checked in the same way. If only the coil is faulty, the air conditioner's fuse is turned off. The coil is removed if it has a screw or clip. The new solenoid coil is placed in place and fixed, and the electrical connection is made. The test is completed by switching the air conditioner to heating mode and seeing that the test heating is performed. There are two separate switches on the training set to fault the outdoor unit fan motor and the outdoor unit fan capacitor. The first step in fault diagnosis is visual inspection. In order to diagnose a fault in a system, it is necessary to know the operating logic of the system and the order in which the components are activated and deactivated. In order for the outdoor unit fan motor to operate, the outdoor unit fan motor control circuit is energized via the relay coil with the signal coming from the electronic card (PCB). When the relay contacts are drawn, 230 AC voltage is supplied to the outdoor unit fan motor. There is a 2.5µF fan capacitor that creates a ninety degree phase difference between the windings in the circuit, increasing the torque. The fan motor has 3 wires; common (C), auxiliary winding (S) and run winding (R) going to the capacitor. The capacitor is connected between the R and S terminals to provide the starting and running torque of the motor. It is possible to check whether the fan motor and fan capacitor are defective by performing a capacitor capacity test and a fan motor winding resistance test with a measuring device. Additionally, the voltage value on the multimeter (AC) should be 230V and the fan blade should be able to rotate freely by hand. With these tests, fan capacitor, motor winding or board failure is reliably detected. If a fan motor replacement is required, a fan motor with the same specifications and capacity must be installed. A fault in the condenser fan or fan motor prevents heat transfer from the condenser. This will reduce condenser efficiency and increase discharge pressure. Figure 7 shows the capacitor failure of the outdoor unit fan motor; Figure 8 shows the system components affected by the outdoor unit fan motor failure. In the outdoor unit fan motor capacitor failure application, the first two experiments show the values under normal conditions. Then, when the fault occurred, the energy consumed increased from 780 watts to 1676 watts (Figure 7a), and the current drawn in the system increased from 3.49 amps to 7.08 amps (Figure 7b). A rapid increase in high pressure was observed as the low pressure increased from 66 psi to 96 psi. After 485 psi, no value could be read (Figure 7c). The condenser gas inlet temperature increased from 69ºC to 86ºC, and the condenser gas outlet temperature increased from 35ºC to 74ºC (Figure 7d). The evaporator gas inlet temperature increased from 13ºC to 16ºC, and the evaporator gas outlet temperature increased from 10ºC to 15ºC (Figure 7e).

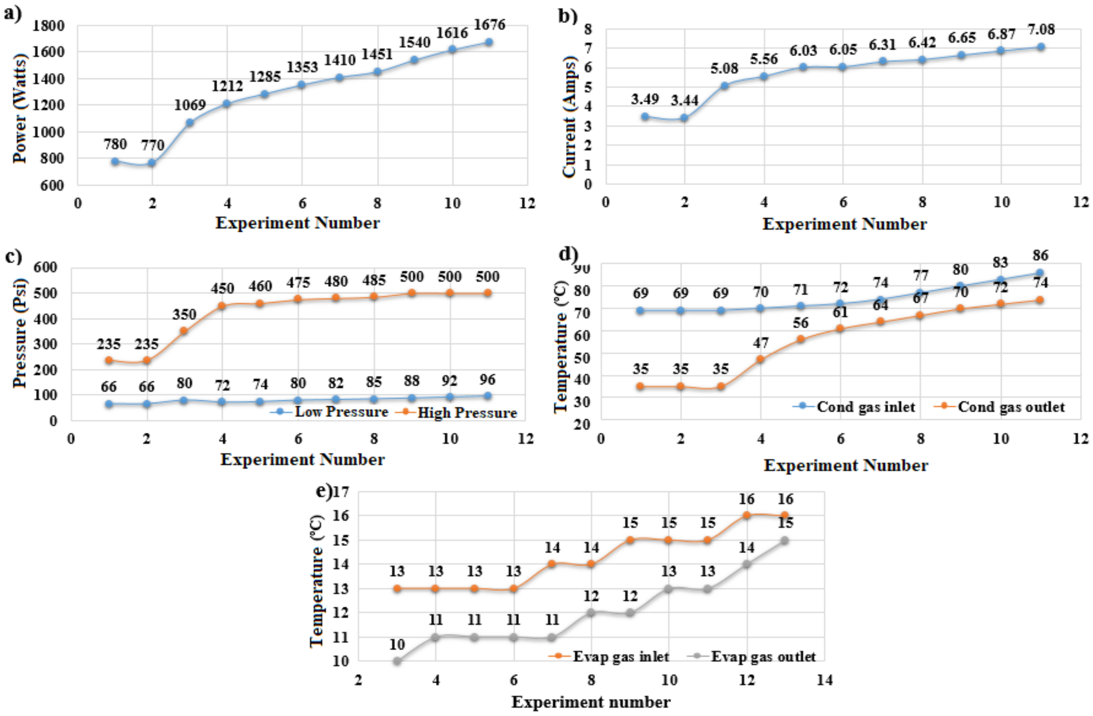

Figure 7. Outdoor unit fan motor capacitor failure

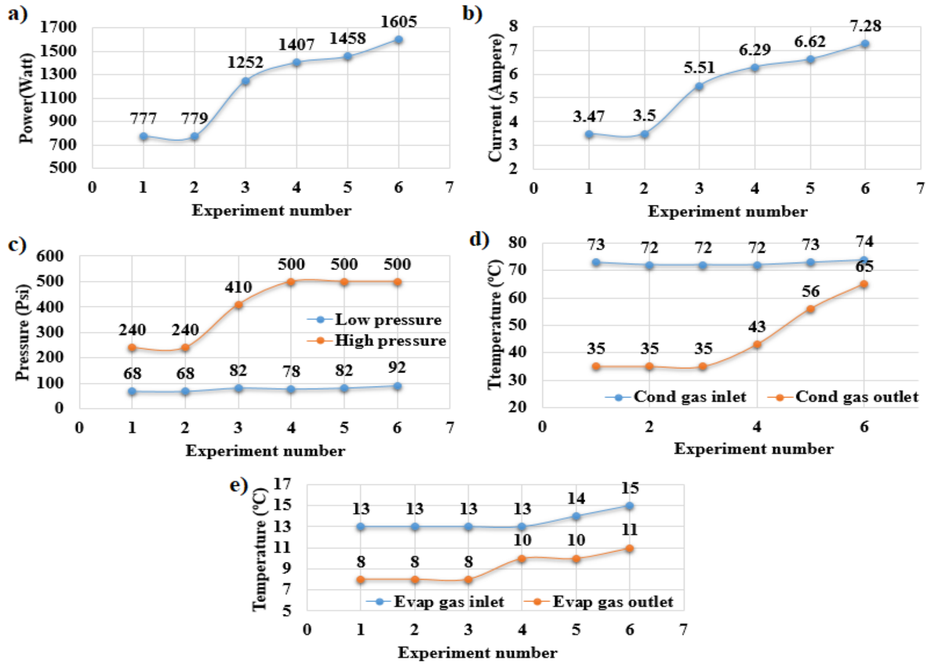

Figure 8. Outdoor unit fan motor failure

When the outdoor unit fan motor malfunctioned after the first two values, the energy consumed by the system increased from 777 watts to 1605 watts (Figure 8a), while the current drawn increased from 3.47 amps to 7.28 amps (Figure 8b). Low pressure increased from 68 psi to 92 psi, and high pressure increased suddenly after 240 psi, reaching the gauge limit (Figure 8c). The condenser gas inlet temperature remained steady at around 73°C, while the condenser gas outlet temperature increased rapidly from 35°C to 65°C (Figure 8d). The evaporator gas inlet temperature increased from 13ºC to 15ºC, and the evaporator gas outlet temperature increased from 8ºC to 11ºC (Figure 8e). In this experiment, the number of experiments is limited because the compressor is quickly disabled.

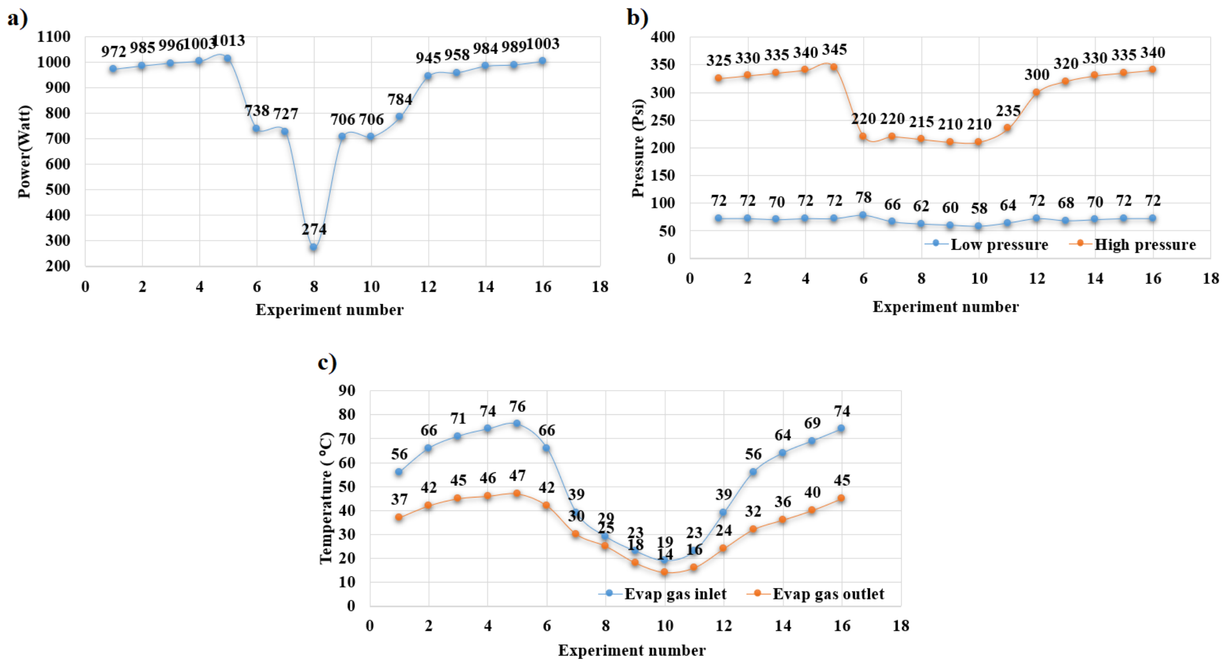

Figure 9. Four-Way valve relay failure

In case of four-way valve relay failure (Figure 9), the system was first operated in heating mode, then the relay coil was de-energized and the fault was signaled, then the fault was resolved and the system was switched to normal heating mode. When the system operated normally, the power value gradually increased from 972 watts to 1013 watts during the test period, and when the fault was given and it was disabled, the energy consumed by the system varied from 738 watts to 706 watts. When the fault was removed, the energy consumed by the system increased from 784 to 1003 Watts (Figure 9a).When the system is in heating mode, the high pressure value is around 335 psi. When the fault was given to the four-way coil, it showed an average change of 215 psi value, and when the fault was removed from the four-way valve, it showed an average change of 320 psi value (Figure 9b). While the system was in heating mode, the evaporator gas inlet temperature increased from 56 ºC to 76 ºC, and when the system malfunctioned, it was observed that it dropped to 19 ºC during the test period. When the fault in the system was removed, the evaporator gas inlet temperature gradually increased to 74 ºC (Figure 9c). The training set includes three separate key components: compressor failure, compressor condenser failure, and compressor main relay failure. Compressor condenser failures are among the most common problems in split air conditioners. The compressor is the fundamental element that completes the vapor compression cycle by compressing the refrigerant, and when it fails, the air conditioner cannot cool or heat. If the compressor is not working, making a buzzing sound, starting and stopping intermittently, or tripping the fuse or thermal overload circuit, the resistances between the C-R-S terminals, the housing insulation, and the current draw are checked. The conformity of the measured values to the catalog values is evaluated. The training set also provides practical training on measuring the compressor windings and identifying the common, main, and auxiliary terminals. The capacitor of the air conditioner compressor is a permanent circuit capacitor and increases the torque by creating a ninety-degree phase difference between the windings. If the capacitor is defective, the compressor cannot start or has difficulty starting. The compressor hums. The compressor runs for a short time and stops, but does not start again. The capacitor body or bottom may be swollen, cracked, burned, or leaking fluid. This may indicate that the capacitor is faulty. In order to detect the fault, the microfarad (μF) value of the capacitor is measured with a multimeter. If the measured value is lower than the value on the capacitor, the capacitor must be replaced. This applies to the indoor and outdoor unit fan and compressor capacities connected to the system, and it is a very important situation to pay attention to. In cases of doubt, a test can be performed with a working capacitor. Capacitors with a value higher or lower than the original value in the system in microfarads (μF) are never used in the system. Air conditioning capacitors may explode due to excessive voltage or temperature. Due to long-term use of the capacitor, its internal structure may age and therefore lose value. For the correct diagnosis of compressor or fan capacitor failure, visual and electrical checks should be performed first, followed by testing with part replacement if necessary. Working carefully and with measuring devices during these checks is essential to accurately detect the fault and ensure the system is in good working order.

If the compressor capacitor fails, the air conditioner cannot perform its heat transfer function. The sound of the compressor changes, and it can be clearly identified from the noise that it is operating under strain. The energy consumed by the compressor increases, and subsequently, the system is damaged. In the experiments, the first two experiments show the operating conditions before the failure. After the fault occurred, the system power draw increased from 785 watts to 876 watts (Figure 10a). The current drawn from the compressor increased from 3.41 amperes to 5.04 amperes (Figure 10b). There was no significant change in pressure values. The condenser gas inlet temperature increased from 59ºC to 65ºC, and the evaporator gas inlet temperature increased from 10ºC to 13ºC (Figure 10c).

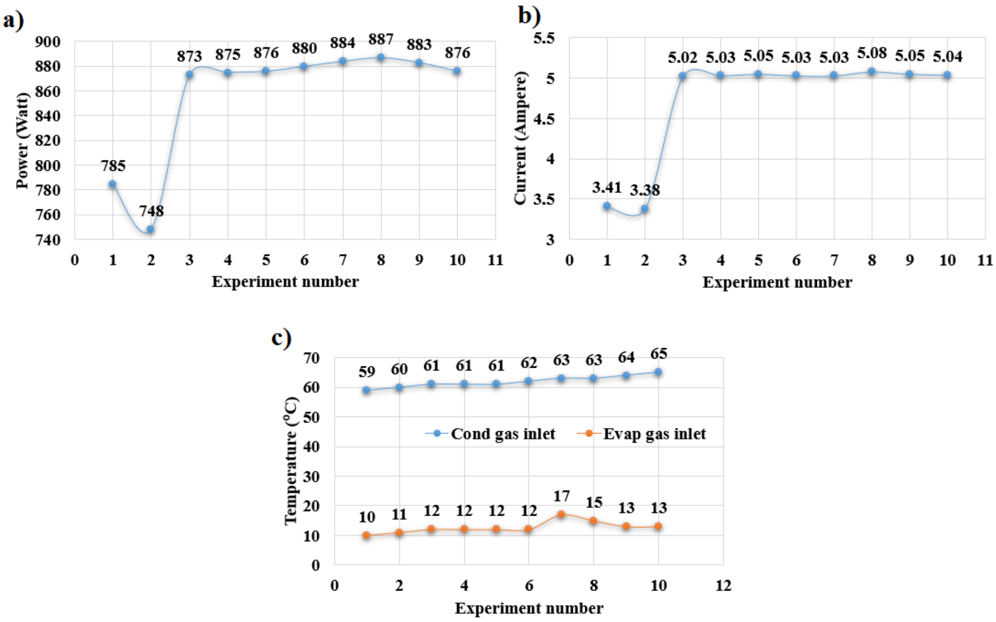

Figure 10. Compressor capacitor failure

The training set includes two fault switches for indoor unit fan motor and indoor unit fan capacitor malfunctions. In the event of a fault, a visual inspection is performed, followed by fault detection training. The fan motor sockets are removed from the card and checked by measuring with a measuring device. The fan capacitor is removed and measured and checked with a measuring device. Values consistent with the catalog specifications must be obtained. Otherwise, there is a fault. The faulty indoor unit fan motor or fan capacitor is replaced with a new one. If the capacitor is soldered onto the fan, soldering a plug-in cable to the board makes installation easier. In Figures 11 and 12, system graphs are given in the wall-type split air conditioner fault detection and service procedures training set in case of indoor unit fan capacitor and indoor unit fan motor failure.

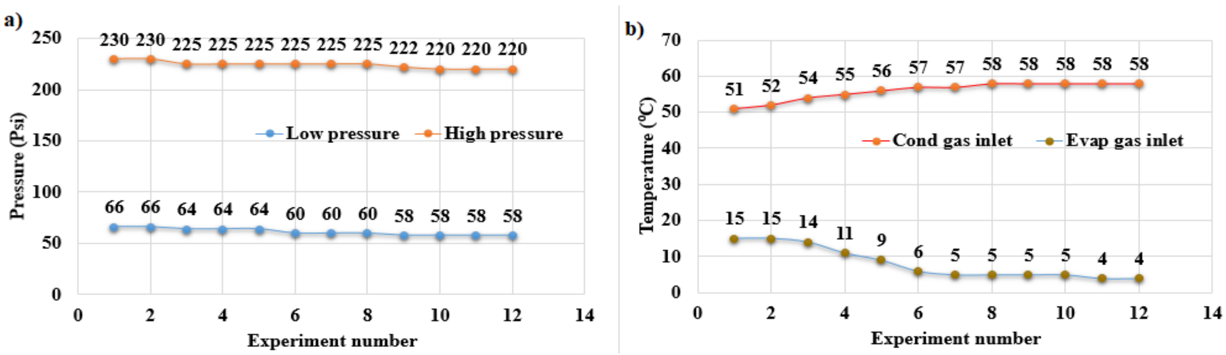

Figure 11. Indoor unit fan capacitor failure

Indoor unit fan capacitor failure, a decrease in low and high pressure values was observed (Figure 11a). The evaporator gas inlet temperature dropped from 15ºC to 4ºC. The condenser gas inlet temperature increased from 51ºC to 58ºC (Figure 11b). In case of indoor unit fan motor failure, it was observed that the power drawn by the system decreased from 740 watts to 570 watts (Figure 12a). High pressure decreased from 230 psi to 180 psi, and low pressure decreased from 66 psi to 20 psi (Figure 12b). The current drawn by the system decreased from 3.34 amperes to 2.53 amperes, and an increase in the power factor (cos φ) value was observed (Figure 12c). The evaporator gas inlet temperature decreased from 16ºC to -10ºC, and the evaporator gas outlet temperature decreased from 11ºC to -5 ºC (Figure 12d).

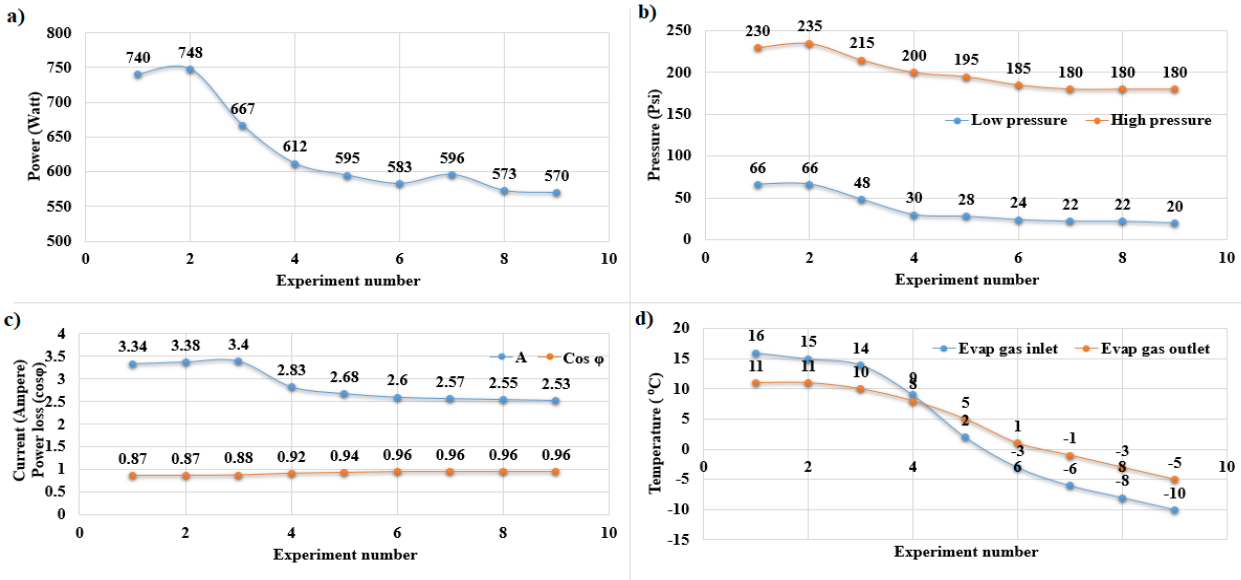

Figure 12. Indoor unit fan motor failure

The training set includes a flap motor fault switch. If there is no movement in the flap motor, it is necessary to check the card output voltage. If there is no voltage at the output, the circuit to which it is connected on the board must be repaired. Additionally, the motor socket is removed for testing the motor resistance. The resistance between the terminals is measured. A very high (∞) measurement indicates a broken winding, a measurement close to 0 indicates a short circuit. A catalogue reading indicates that the motor winding is intact. It should be checked for movement and stopping at the desired position. The microprocessor supported by the software on the training set converts the commands it receives from the user into electrical signals and sends signals to other equipment in the air conditioning system (compressor, four-way valve, fan motor, etc.) in a certain order, ensuring that the system operates at the set value. When removing the electronic card, the microprocessor on the electronic card should not be touched with bare hands. Otherwise, static electricity accumulated on the human body may cause the microprocessor to malfunction. If there is a complete disorder in the operation of the system, the fault may be in the microprocessor. After checking the entire circuit, if there is no fault in the other elements of the circuit and no problem is observed in the control and power supply of the microprocessor, there is a high probability that the microprocessor is faulty. If a fault occurs, the entire board must be replaced. The training set includes two fault switches (numbers 6 and 7) for the pipe and ambient sensors. Checking the sensors is done by measuring the resistance with a measuring device after the card connection is disconnected. The resistance change with temperature in NTC sensors should also be checked. If a fault is detected, it is replaced with a pipe and an ambient sensor of the same ohm value. The training set includes a display board and a fault switch. The display card detects the control signals coming from the user and transmits them to the microprocessor. The infrared (IR) receiver on the board receives signals from the remote control and transmits them to the electronic circuit board. If the test switch on the display card is in the on position, the display is completely turned off, meaning no power is supplied to the display. In this case, the screen does not light up at all. Fault checking begins with a visual inspection of the socket connections and the card. Then, the power supply to the board is checked using a multimeter. If voltage is present but the screen does not operate, the display board may be faulty and needs to be replaced. The most common failure observed in display boards is LED burnout. The defective LED is removed from the board and a new one is soldered in its place. If the control signals are not being detected, the infrared receiver (sensor) on the board may be faulty. Additionally, if the air conditioner continues operating normally but the display shows no information at all, this indicates a malfunction in the display circuit. In this case, the display board or the other faulty board usually needs to be replaced.

In studies on split air conditioning systems, while fault detection training mostly consists of theoretical explanations, there are also a limited number of studies [9,10,16] that provide experimental application opportunities. In a similar study, Cingiz et al. (2025) determined that the fault detection time was significantly reduced thanks to the applications made in training sets. The literature [17,18] states that failures in compressors and auxiliary electrical components are among the frequently encountered problems in split air conditioning systems, and that accurate diagnosis of these failures is important for energy efficiency and system safety. It has been observed that, thanks to the controlled fault simulations created, basic diagnostic steps can be applied consciously. These types of hands-on training sets provide a better understanding of the fault detection process compared to theoretical training, helping to make quick and accurate interventions. Therefore, it is believed that the developed training set will make a significant contribution to improving fault diagnosis skills for air conditioning systems in vocational and technical education.

4. CONCLUSION

Wall-mounted split air conditioners, one of the most widely used air conditioning devices in Türkiye, are frequently preferred in both residential and commercial areas. This situation increases the need for qualified technical personnel for service, maintenance, and repair operations. The "Wall Type Split Air Conditioner Fault Detection and Service Procedures Training Set" was developed to directly respond to this need; It is a teaching material that combines electrical, electronic and automatic control information with practical scenarios, including fault detection, maintenance and repair processes. Thanks to the training set, students gain the competence to recognize, detect and produce solutions to the faults they may encounter in real air conditioning systems. In the training set, basic electrical fault types are created and how to test them with measuring devices is explained in practice, so that students and technical personnel who will receive training have access to the knowledge to produce conscious and effective solutions to real fault scenarios. Experiments conducted on the training set have shown that the amount of refrigerant charge and electrical and mechanical component failures in split air conditioning systems play a decisive role in system performance. The integrated electrical testing equipment and temperature and pressure measuring devices enable the system to be used effectively not only in vocational training but also in academic research. Thanks to its design suitable for domestic production, the training set ensures sustainability in technical education, reduces dependence on imports, trains qualified personnel, and supports domestic industry and national technological independence. The results obtained in the applications showed that excessive or insufficient refrigerant charge negatively affects system pressures and compressor operating conditions, increasing energy consumption, reducing cooling capacity, and leading to compressor overheating. Measurement results and graphs reveal that changes in pressure differences are directly related to compressor load and energy efficiency. Furthermore, it was determined that fan, condenser, and four-way valve failures negatively affect heat transfer, causing the system to lose its operational balance; outdoor and indoor unit fan failures and condenser failures cause the compressor to draw higher current and be under strain; and in the case of a four-way valve failure, the heating function is disabled. These results reveal the effects of failure scenarios in the system, while also contributing to the development of qualified technical personnel who can think analytically, effectively respond to failures, and possess high practical skills, thereby increasing the quality and efficiency of vocational training.

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DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethics committee and/or legal or special permissions.

CONTRIBUTION OF THE AUTHORS

Ganime Tuğba Önder: Conducted the risk analysis and wrote the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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