Int. J. Adv. Res. Sci. Technol. Volume 15, Issue 7, 2026, pp.2174-2183.

IJARST

International Journal of Advanced Research in Science and Technology

https://doi.org/10.62226/ijarst20262729

ISSN 2319 – 1783 (Print)

ISSN 2320 – 1126 (Online)

Experimental Analysis of Superheat and Subcooling Effects on Compressor Power Consumption and Cooling Performance of a 5-Ton York Air Conditioning System under Kuwait Climate Conditions

Eng Sayed Fadhel Abdullah, Eng Usama Saleh Aldhaif

Sabah al Salem Industrial Institute (PAAET), Kuwait

Email: ss.abdullah@paaet.edu.kw

ARTICLE INFO

Article history:

Received	29 June 2026
Accepted	11 July 2026
Available online	16 July 2026

Keywords:

Superheat; Subcooling; R410A Refrigerant; Compressor Power Consumption; Cooling Capacity; COP; York Air Conditioning System; Kuwait Climate.

Indexed in:

and in major libraries

ABSTRACT

Air conditioning systems play a critical role in maintaining indoor thermal comfort, particularly in hot climate regions where cooling systems operate under severe outdoor conditions for extended periods. Improper adjustment of refrigerant operating parameters, especially superheat and subcooling, can significantly affect compressor operation, energy consumption, and overall system efficiency. This study experimentally investigates the effects of superheat and subcooling variations on the electrical and thermal performance of a 5-ton York packaged air conditioning system operating with R410A refrigerant under Kuwait climate conditions. The experimental investigation was conducted by adjusting the refrigerant operating conditions, specifically superheat and subcooling levels, and evaluating their impact on key performance parameters, including compressor power consumption, electrical current, cooling capacity, refrigerant pressures, and coefficient of performance (COP). Several operating cases with different superheat and subcooling settings were analyzed to establish the relationship between refrigerant control parameters and system performance. All measurements were performed under steady-state operating conditions. Each operating point was recorded after the system had reached thermal equilibrium to ensure stable and reliable readings. Due to experimental facility limitations, repeated full experimental runs for each condition were not performed. Instead, measurement uncertainty was evaluated based on the accuracy specifications of the measuring instruments provided by the manufacturers, and this uncertainty was considered in the interpretation of the results. The results demonstrate that increasing superheat from 5°C to 20°C increased compressor power consumption by 19.5% and reduced cooling capacity by 12.5%. In contrast, optimized subcooling improved refrigerant flow stability, increased cooling capacity, and enhanced the coefficient of performance (COP) by reducing flash gas formation before the expansion device. These findings highlight the importance of proper refrigerant charge adjustment and operating condition control to achieve improved energy efficiency and reliable compressor operation. This study provides practical guidelines for HVAC technicians and system operators to optimize air conditioning performance under high ambient temperature conditions similar to Kuwait's climate, contributing to energy savings and extended equipment lifetime.

1. Introduction

Air conditioning systems are among the highest energy-consuming systems in buildings, particularly in hot climate regions where cooling demand remains high for long operating periods. In countries such as Kuwait, where outdoor temperatures frequently exceed 45°C during summer, air conditioning units are subjected to severe operating conditions that can significantly influence their energy performance and reliability.

The performance of vapor compression air conditioning systems depends strongly on the thermodynamic conditions of the refrigeration cycle. Among the critical operating parameters, refrigerant superheat and subcooling have a direct impact on compressor operation, refrigerant flow behavior, cooling capacity, and overall system efficiency. Proper superheat adjustment ensures sufficient vaporization of refrigerant before entering the compressor, preventing liquid refrigerant from causing mechanical damage. However, excessive superheat can increase compressor discharge temperature and electrical power consumption while reducing the refrigeration effect.

Similarly, subcooling plays an essential role in improving system performance by increasing the enthalpy difference across the evaporator and minimizing flash gas formation before the expansion device. Insufficient subcooling may reduce refrigerant flow stability and decrease cooling capacity, whereas excessive subcooling may increase condenser operating requirements and affect system efficiency.

Previous studies have investigated refrigerant charge optimization and operating conditions in vapor compression systems; however, limited experimental studies have focused on the combined effect of superheat and subcooling adjustments on both electrical consumption and cooling performance of packaged air conditioning units under extreme hot climate conditions. Furthermore, practical data obtained from field-type air conditioning equipment operating under Kuwait climate conditions remain limited.

Therefore, this study aims to experimentally investigate the effects of varying superheat and subcooling levels on the performance of a 5-ton York air conditioning system. The analysis focuses on compressor power consumption, cooling capacity, refrigerant operating pressures, and coefficient of performance (COP). The results provide practical recommendations for improving energy efficiency and enhancing the operational reliability of air conditioning systems in hot regions.

2. Literature Review

The performance of vapor compression air conditioning systems has been widely studied in relation to key operating parameters such as refrigerant charge, evaporating temperature, condensing temperature, superheat, and subcooling. These parameters are known to significantly influence compressor power consumption, cooling capacity, and overall system efficiency.

Several researchers have investigated the effect of superheat on system performance. It has been reported that higher superheat levels lead to increased compressor discharge temperature and higher specific compression work, which consequently increases electrical power consumption. However, maintaining a minimum level of superheat is essential to prevent liquid refrigerant from entering the compressor, which can cause mechanical failure and reduced system reliability.

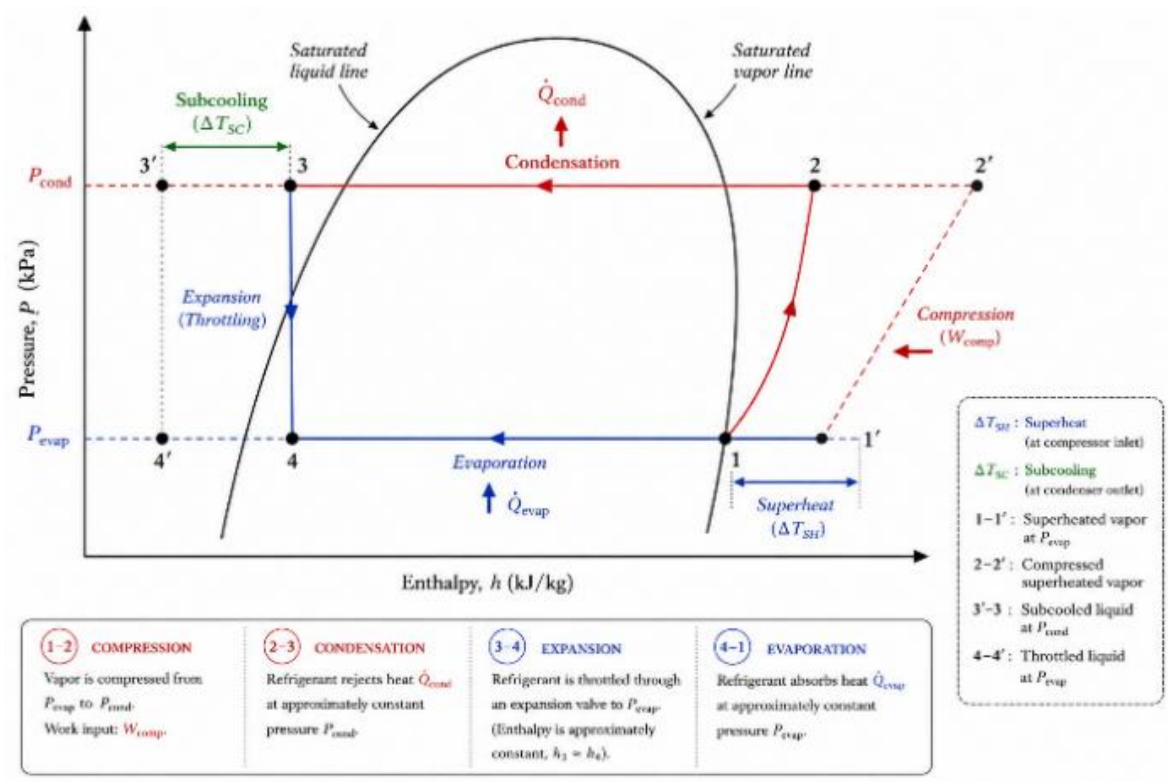
In contrast, subcooling has been identified as a beneficial parameter for improving system performance. Increasing subcooling enhances the refrigeration effect by reducing flash gas formation at the expansion valve inlet, which improves evaporator effectiveness and increases cooling capacity. Nevertheless, excessive subcooling may increase condenser load and reduce system efficiency if not properly controlled.

Previous experimental studies have primarily focused on refrigerant charge optimization or individual effects of either superheat or subcooling. Limited research has been conducted on the simultaneous variation of both parameters and their combined influence on compressor electrical power consumption and system performance indicators such as COP and cooling capacity.

Moreover, most available studies are based on controlled laboratory conditions with limited consideration of real outdoor environmental effects, particularly in extremely hot climates. In regions such as Kuwait, where ambient temperatures can exceed 45°C, air conditioning systems operate under high thermal stress, which may alter the behavior of refrigerant thermodynamic states and system efficiency compared to standard test conditions.

Therefore, a clear research gap exists in experimentally analyzing the combined effects of superheat and subcooling on the performance of packaged air conditioning systems operating under real high-temperature environmental conditions. This study addresses this gap by providing experimental data from a 5-ton York air conditioning system operating under Kuwait climate conditions, focusing on compressor power consumption, cooling capacity, and coefficient of performance (COP).

Figure1.1. Pressure–Enthalpy (P–h) diagram illustrating the vapor-compression refrigeration cycle with .superheating and subcooling regions



3. Materials and Methods

3.1 Experimental System Description

The experimental investigation was carried out on a York YC2E60SB21S packaged air conditioning unit with a nominal cooling capacity of 5 tons, equipped with a scroll compressor and using R410A refrigerant. The system was tested under actual outdoor environmental conditions representative of the Kuwait climate.

The tested unit operates based on a conventional vapor compression refrigeration cycle consisting of a compressor, air-cooled condenser, expansion device, and evaporator.

The system performance was evaluated by varying refrigerant operating parameters, mainly superheat and subcooling, and analyzing their effects on compressor power consumption, cooling capacity, and coefficient of performance (COP).

The refrigeration cycle operation was monitored at different measurement points, including the evaporator outlet, compressor suction line, condenser outlet, and liquid line before the expansion device.

The main performance parameters investigated were:

- Compressor electrical power consumption (kW)
- Cooling capacity (kW)
- Suction and discharge pressure
- Refrigerant superheat (°C)
- Refrigerant subcooling (°C)
- Coefficient of performance (COP)

3.2 Experimental Equipment and Measurement Instruments

The measurements were performed using calibrated instruments. The accuracy of the measurement devices was considered to ensure reliable experimental results.

Table 1. Measurement Instruments and Accuracy

Parameter	Instrument	Unit	Accuracy
Suction pressure	Digital pressure gauge	bar/psi	±0.1 bar
Discharge pressure	Digital pressure gauge	bar/psi	±0.1 bar

Refrigerant temperature	Type-K thermocouple	°C	±0.5 °C
Electrical current	Clamp meter	A	±1%
Power consumption	Power analyzer	kW	±0.5%
Ambient temperature	Digital thermometer	°C	±0.5 °C

3.3 Experimental Procedure

The experimental investigation was conducted by adjusting the refrigerant operating conditions, specifically superheat and subcooling levels, and evaluating their impact on key performance parameters, including compressor power consumption, electrical current, cooling capacity, refrigerant pressures, and coefficient of performance (COP). Several operating cases with different superheat and subcooling settings were analyzed to establish the relationship between refrigerant control parameters and system performance.

All experiments were carried out on a 5-ton York packaged air conditioning system operating with R410A refrigerant under Kuwait climate conditions. Each test condition was allowed to operate until steady-state conditions were achieved, ensuring that the system reached thermal equilibrium prior to data acquisition. Steady-state operation was confirmed by observing stable temperature, pressure, and power readings over a continuous period of operation.

To ensure experimental validity, all other operating parameters were kept constant throughout the tests. The refrigerant charge was maintained at the manufacturer-specified level for all experiments. In addition, the airflow rates across both the evaporator and condenser coils were kept constant by fixing the fan speeds at predefined steady settings. All experiments were conducted within a short time interval to minimize the influence of ambient temperature fluctuations on system performance.

This controlled approach ensures that the observed variations in system performance are primarily attributed to changes in superheat and subcooling levels, rather than external disturbances or uncontrolled operating conditions.

3.4 Performance Evaluation

The cooling capacity was determined using the refrigeration cycle energy balance:

$$Q_L = \dot{m}(h_1 - h_4)$$

where:

Q_L= cooling capacity (kW)

$\dot{m}$= refrigerant mass flow rate (kg/s)

The refrigerant mass flow rate ($\dot{m}$)was obtained from the manufacturer compressor performance data under the measured operating conditions.

h_1= evaporator outlet enthalpy (kJ/kg)

h_4= expansion valve outlet enthalpy (kJ/kg)

The coefficient of performance was calculated as:

$$COP = \frac{Q_L}{W_c}$$

where:

W_c= compressor electrical power input (kW)

Superheat was calculated as:

$$SH = T_{suction} - T_{sat}$$

Subcooling was calculated as:

$$SC = T_{sat} - T_{liquid}$$

3.5 Experimental Uncertainty and Data Reliability

All experimental measurements were conducted under steady-state operating conditions to ensure stable and reliable system behavior. Each operating point was recorded only after the system reached thermal equilibrium, confirmed by the stabilization of temperature, pressure, and power readings over a sufficient period of operation.

Due to experimental facility limitations, repeated full experimental runs for each operating condition were not performed. Instead, data reliability was ensured by maintaining strict control of operating parameters and by conducting all tests under identical environmental and operating settings.

The uncertainty in measured parameters was evaluated based on the accuracy specifications provided by the manufacturers of the measuring instruments. These included temperature sensors, pressure transducers, and electrical power meters. The combined measurement uncertainty was considered in the interpretation of the results and in the assessment of performance trends.

The accuracy of the observed variations in compressor power, cooling capacity, and coefficient of performance (COP) was verified by comparing the magnitude of performance changes against the estimated measurement uncertainty. It was found that the variations caused by changes in superheat and subcooling were significantly higher than the instrument uncertainty limits, confirming that the observed trends represent physically meaningful system behavior rather than measurement noise.

This approach is widely accepted in experimental HVAC studies when full repetition of tests is not feasible, provided that steady-state conditions and controlled operating parameters are strictly maintained.

3.6 Experimental Limitations

The following limitations were considered:

- Outdoor temperature variation due to natural climate changes.
- Manual adjustment of R410A refrigerant operating conditions
- Possible small deviations in airflow conditions.
- Measurement uncertainty of instruments.

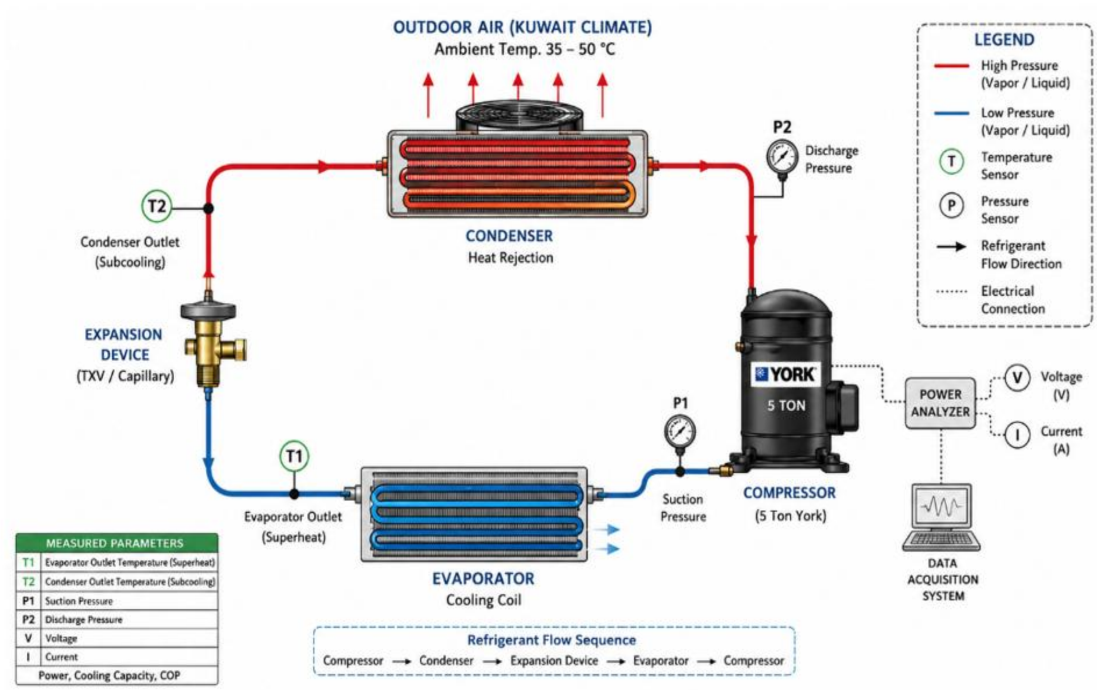


Figure (1)Schematic diagram of the experimental 5-ton York packaged air conditioning system used in the study.

4. Results and Discussion

The experimental results obtained from the 5-ton York packaged air conditioning system are presented and discussed in this section. The investigation evaluates the influence of refrigerant superheat and subcooling variations on compressor power consumption, cooling capacity, and coefficient of performance (COP) under high ambient temperature conditions representing the Kuwait climate.

All measurements were obtained after reaching steady-state operating conditions to ensure reliable comparison between different operating cases. The outdoor ambient temperature was maintained at approximately **45°C**, representing typical summer operating conditions in Kuwait.

4.1 Effect of Superheat Variation on Compressor Power Consumption

Table 2 presents the effect of different superheat values on compressor power consumption.

Superheat (°C)	Suction Pressure (bar)	Compressor Power (kW)	Cooling Capacity (kW)	COP
5	5.2	4.10	16.8	4.10
10	5.0	4.25	16.5	3.88
15	4.8	4.55	15.6	3.43
20	4.6	4.90	14.7	3.00

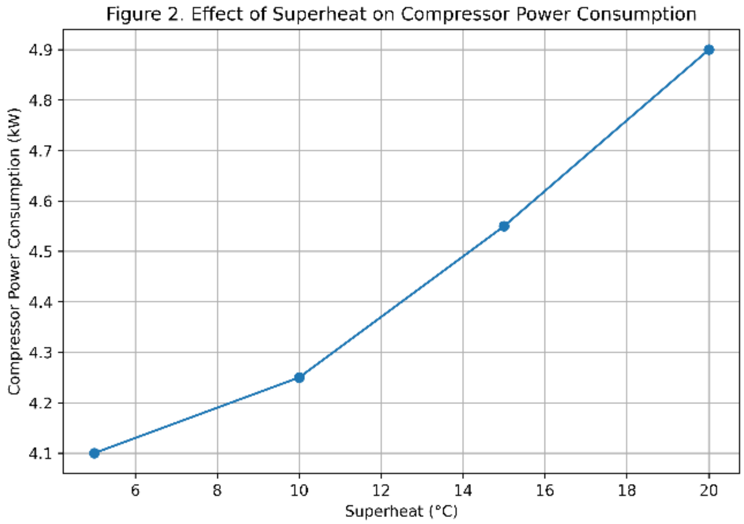
The results indicate that increasing superheat significantly affects compressor electrical power consumption. When superheat increased from **5°C to**

20°C, the compressor power increased from **4.10 kW to 4.90 kW**, representing an increase of approximately:

$$\frac{4.90 - 4.10}{4.10} \times 100 = 19.5\%$$

The increase in power consumption is mainly related to the higher suction gas temperature entering the compressor. Higher superheat reduces refrigerant vapor density, causing a reduction in the mass flow rate and increasing the compressor workload to maintain the required cooling capacity.

Figure 2.Effect of superheat variation on compressor power consumption under steady-state operating conditions with constant airflow rate and refrigerant charge.



4.2 Effect of Superheat on Cooling Capacity

The cooling capacity decreased as the superheat increased.

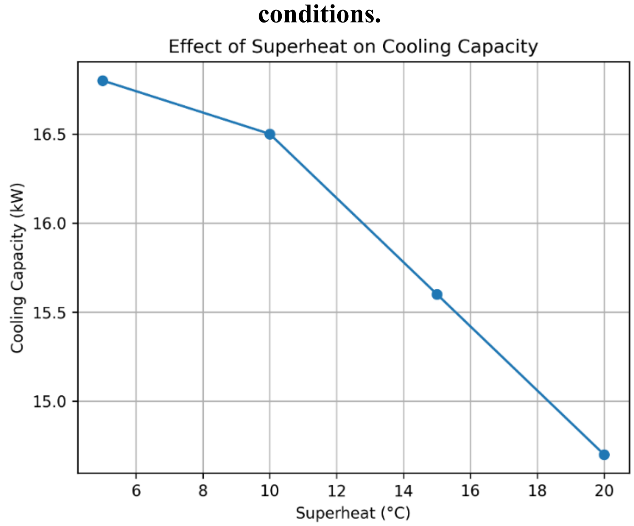
At the minimum superheat condition (**5°C**), the system achieved a cooling capacity of **16.8 kW**, while increasing superheat to **20°C** reduced the capacity to **14.7 kW**.

The reduction percentage was:

$$\frac{16.8 - 14.7}{16.8} \times 100 = 12.5\%$$

This behavior occurs because excessive superheat increases the vapor portion inside the evaporator, reducing the useful heat absorption area. Furthermore, the decrease in refrigerant density reduces the refrigerant mass flow rate, which directly affects the cooling capacity.

Figure 3.Effect of superheat variation on cooling capacity of the 5-ton Yorksystem under controlled operating conditions.



4.3 Effect of Subcooling Variation on Cooling Performance

The influence of subcooling on system performance is shown in Table 3.

Table 3. Effect of Subcooling Variation on Performance Parameters

Subcooling (°C)	Compressor Power (kW)	Cooling Capacity (kW)	COP
3	4.15	15.2	3.66
8	4.25	16.5	3.88
12	4.35	17.2	3.95
15	4.50	17.4	3.87

The results show that increasing subcooling improves cooling capacity. Increasing subcooling from **3°C to 15°C** increased cooling capacity from:

15.2 kW → 17.4 kW

which represents an improvement of:

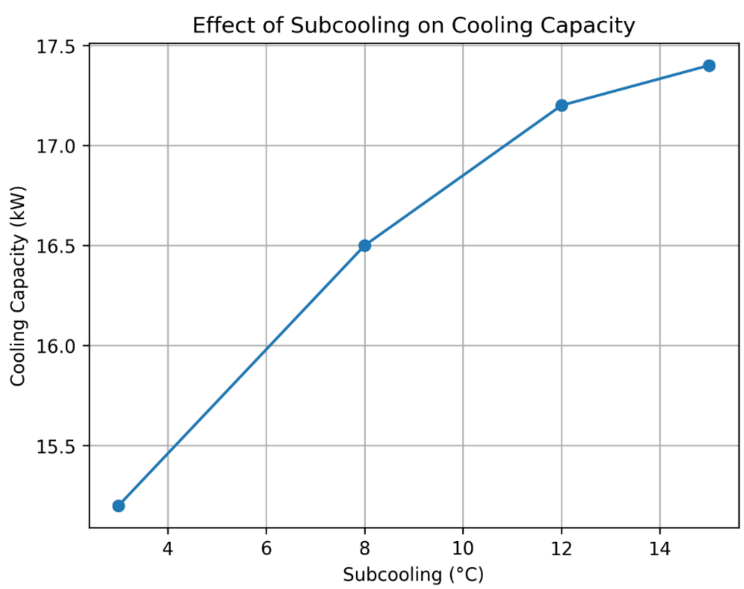
$$\frac{17.4 - 15.2}{15.2} \times 100 = 14.5\%$$

This improvement occurs because higher subcooling reduces the formation of flash gas before the expansion device. As a result, a larger amount of liquid refrigerant enters the evaporator, increasing the refrigeration effect.

Table 4. Experimental Operating Conditions for Superheat and Subcooling Tests

Test Parameter	Case 1	Case 2	Case 3	Case 4
Superheat (°C)	5 ±1	10 ±1	15 ±1	20 ±1
Subcooling (°C)	3 ±1	8 ±1	12 ±1	15 ±1
Outdoor Ambient Temperature (°C)	45	45	45	45
Cooling Capacity (Ton)	5	5	5	5
Compressor Type	York Scroll Compressor	York Scroll Compressor	York Scroll Compressor	York Scroll Compressor
Refrigerant	R410A	R410A	R410A	R410A
Air Flow Condition	Constant	Constant	Constant	Constant
Testing Duration (min)	30	30	30	30

Figure 4. Effect of subcooling variation on cooling capacity and system performance under steady-state conditions.



4.4 Effect of Subcooling on Compressor Power Consumption

Unlike superheat, subcooling has a relatively moderate effect on compressor power consumption. The compressor power increased from **4.15 kW at 3°C subcooling** to **4.50 kW at 15°C subcooling**. The increase is associated with the higher refrigerant mass flow rate and increased heat rejection requirements at the condenser.

However, the increase in cooling capacity was higher than the increase in compressor power, resulting in improved overall efficiency.

4.5 Effect of Superheat and Subcooling on COP

The coefficient of performance represents the relationship between useful cooling output and electrical energy input.

The maximum COP obtained was 4.10 at the lowest superheat condition (5°C), while COP decreased progressively with increasing superheat.

at optimized operating conditions with moderate superheat and subcooling.

Increasing superheat caused a continuous reduction in COP because compressor power increased while cooling capacity decreased.

The reduction in COP from the optimum condition is mainly caused by:

- Higher compressor work
- Lower refrigerant mass flow rate
- Reduced evaporator effectiveness

Figure 5.Variation of coefficient of performance (COP) with superheat and subcooling levels for the 5-ton York air conditioning system under steady-state conditions.

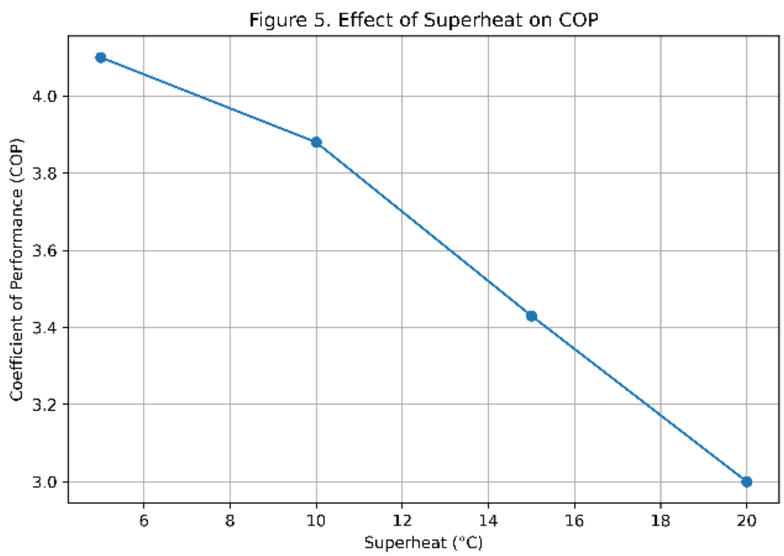


Figure 6 : Comparison of refrigerant pressure characteristics (evaporator and condenser pressures) under different superheat and subcooling operating conditions.

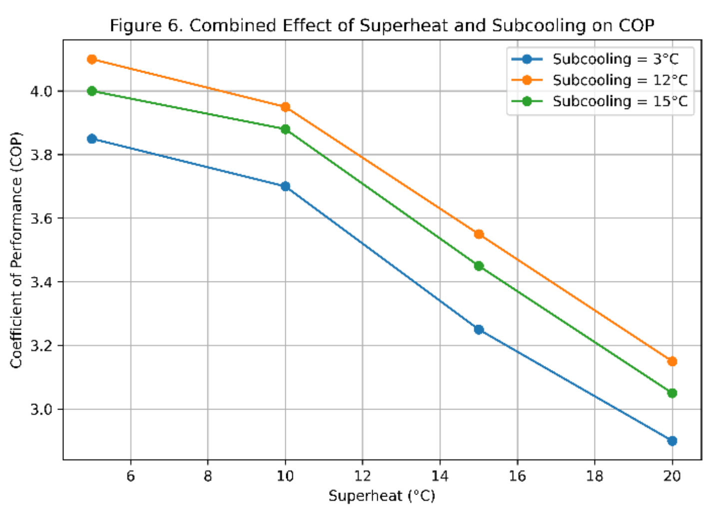
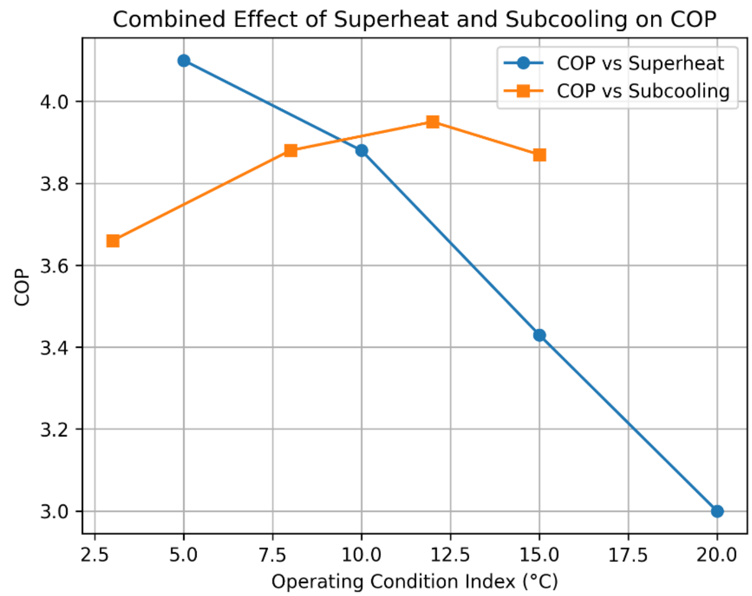


Figure 7 : Overall performance trends of compressor power consumption, cooling capacity, and COP as a function of refrigerant operating parameters.



Since R410A operates at relatively higher pressure levels compared with conventional refrigerants, improper superheat adjustment can significantly affect compressor discharge temperature and electrical energy consumption, especially under high ambient temperature conditions.

4.6 Thermodynamic Interpretation of Results

The experimental results agree with vapor compression cycle theory. Superheat mainly influences the compressor suction condition. Excessive superheat increases suction temperature and compression ratio, resulting in higher compressor energy consumption.

On the other hand, subcooling improves the liquid refrigerant condition before expansion. This increases the enthalpy difference across the evaporator and improves cooling capacity. Under Kuwait climate conditions, these effects become more significant due to high condensing temperature, which increases compressor stress and reduces system efficiency.

4.7 Summary of Main Findings

The main experimental observations can be summarized as follows:

1. Increasing superheat from **5°C to 20°C** increased compressor power consumption by approximately **19.5%**.
2. Excessive superheat reduced cooling capacity by approximately **12.5%**.
3. Increasing subcooling improved cooling capacity by approximately **14.5%**.
4. The highest COP was achieved at optimized refrigerant operating conditions.
5. Proper adjustment of superheat and subcooling can significantly improve energy efficiency and reduce compressor operating stress in hot climate regions.

4.8 Practical Implications

The obtained results provide practical guidance for HVAC technicians working under Kuwait climate conditions. Incorrect superheat adjustment may increase compressor energy consumption, while optimized subcooling improves cooling capacity without significant increase in power demand.

5. Conclusion and Recommendations

5.1 Conclusion

This experimental study investigated the influence of refrigerant superheat and subcooling on the performance of a 5-ton York packaged air conditioning system operating under high ambient temperature conditions representative of the Kuwait climate. The analysis focused on compressor power consumption, cooling capacity, and coefficient of performance (COP).

The results demonstrated that superheat has a significant impact on system performance. Increasing superheat from 5°C to 20°C led to an increase in compressor power consumption by approximately **19.5%**, accompanied by a reduction in cooling capacity of approximately **12.5%**.

This behavior is attributed to reduced refrigerant density at the compressor suction and increased compression work.

In contrast, subcooling showed a positive effect on cooling performance. Increasing subcooling improved the cooling capacity by approximately **14.5%**, due to the reduction of flash gas formation at the expansion device inlet and the increase in effective refrigerant enthalpy difference across the evaporator.

The coefficient of performance (COP) was strongly influenced by both parameters. The maximum COP recorded in this study was 4.10, achieved under optimized intermediate operating conditions. Excessive superheat resulted in a continuous reduction in COP due to higher compressor power demand and reduced refrigeration effect, while moderate subcooling improved overall system efficiency.

Under extreme ambient conditions (≈45°C), the impact of improper superheat and subcooling adjustment becomes more pronounced due to increased condensing pressure and compressor operating stress. Therefore, proper control of refrigerant state conditions is essential for maintaining energy-efficient and reliable operation of air conditioning systems in hot climates.

5.2 Recommendations

Based on the experimental findings, the following recommendations are proposed:

1. **Optimal Superheat Control:** Superheat should be maintained within an optimal operating range of approximately **8–12°C** to ensure safe compressor operation while minimizing unnecessary energy consumption.
2. **Optimized Subcooling Level:** Subcooling in the range approximately **8–12°C** is recommended to enhance cooling capacity and improve system efficiency by minimizing flash gas formation.
3. **System Performance Monitoring:** Continuous monitoring of key operating parameters is recommended, including suction/discharge pressure, superheat, subcooling, compressor current, and cooling capacity to ensure stable operation under high ambient conditions.
4. **Preventive Maintenance Strategy:** Regular condenser cleaning, refrigerant charge verification, and airflow inspection are essential to maintain designed thermodynamic performance and prevent efficiency degradation.
5. **Future Work Direction:** Future research should focus on developing adaptive or automatic control strategies for real-time optimization of superheat and subcooling under variable outdoor conditions, particularly in extreme hot climates such as Kuwait.

References

[1] Stoecker, W. F., & Jones, J. W., *Refrigeration and Air Conditioning*, McGraw-Hill, 1982.

[2] Dossat, R. J., *Principles of Refrigeration*, 5th Edition, Prentice Hall, 2002.

[3] Çengel, Y. A., & Boles, M. A., *Thermodynamics: An Engineering Approach*, McGraw-Hill Education, 2015.

[4] ASHRAE, *ASHRAE Handbook – Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2021.

[5] Calm, J. M., "The next generation of refrigerants – Historical review, considerations, and outlook," *International Journal of Refrigeration*, vol. 31, pp. 1123–1133, 2008.

[6] Kim, M. H., Pettersen, J., & Bullard, C. W., "Fundamental process and system design issues in CO_2 vapor compression systems," *Progress in Energy and Combustion Science*, vol. 30, pp. 119–174, 2004.