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Evaluation of the Impact of Sandstorms on Air-Conditioning System Energy Efficiency and Power Consumption under Kuwait Climatic Conditions

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ABSTRACT

This study investigates the impact of sandstorms on the operational performance, thermodynamic efficiency, and power consumption of central air-conditioning systems operating under extreme desert conditions in Kuwait. Experimental field measurements were conducted on a 10-ton (120,000 BTU/h) rooftop packaged unit manufactured by York International during the peak summer months (June–August) of 2024 and 2025 in Bayan District, Hawalli Governorate. The study evaluates the influence of ambient temperature, relative humidity, and airborne dust deposition on condenser heat rejection, refrigerant pressures (low pressure, LP; high pressure, HP), compressor discharge temperature, subcooling behavior, and electrical current draw. Under normal operation at 48°C ambient temperature, high-side pressure was recorded at 275 PSIG. During sandstorm-induced condenser fouling, high-side pressure increased to approximately 350 PSIG, accompanied by elevated compressor discharge temperature and increased power consumption. The results confirm that sand accumulation significantly degrades condenser heat transfer efficiency, increases compression ratio, and raises compressor workload. Preventive maintenance and periodic condenser cleaning were found to restore operational efficiency, reduce power consumption, and extend system lifespan in desert climates.

1. INTRODUCTION

Climate change has significantly influenced global energy systems, particularly in arid and semi-arid regions. Kuwait experiences extreme summer temperatures exceeding 50°C, combined with frequent sandstorms and high airborne particulate concentration. These environmental stressors place severe operational demands on HVAC systems. Air-conditioning systems operate based on the vapor compression cycle, in which heat rejection at the condenser is critical to system efficiency; any reduction in condenser heat transfer capability results in elevated condensing temperature and pressure, increasing compressor workload and electrical energy consumption. This study presents empirical field data quantifying the performance degradation of a central air-conditioning unit operating under real sandstorm conditions in Kuwait.

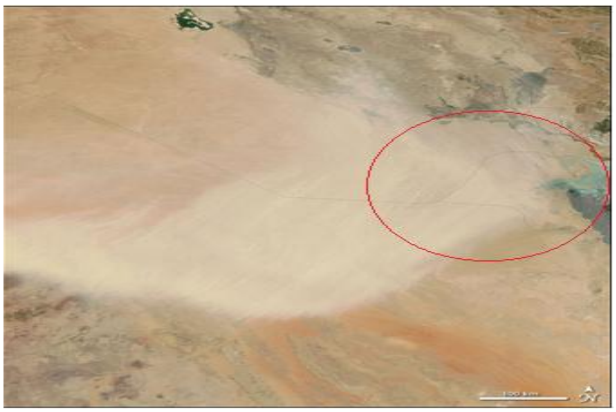
2. LITERATURE REVIEW

2.1 Impact of Ambient Temperature on HVAC Performance

Ambient temperature is one of the most influential parameters affecting condenser performance. As outdoor temperature increases, the temperature gradient between the condenser surface and ambient air decreases, reducing the convective heat transfer rate, consistent with Newton's law of cooling. Previous research indicates that compressor power consumption may increase by 5–15% for every 1°C rise above design ambient temperature in hot climate regions

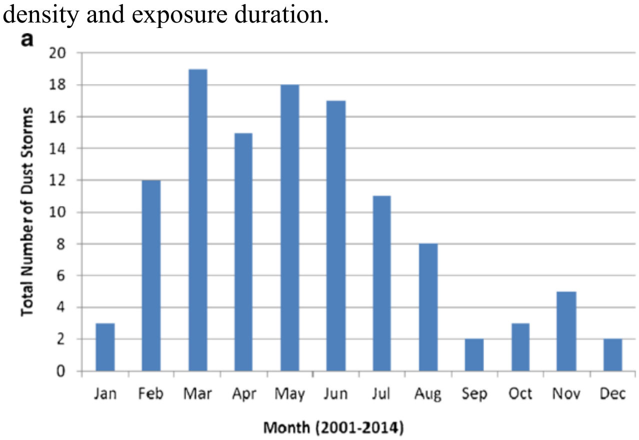
2.2 Effect of Dust and Sandstorm Particles on Heat Transfer Surfaces

Dust accumulation on condenser coils forms an insulating layer, reducing the heat transfer coefficient. In desert environments, sand particles obstruct airflow through condenser fins, resulting in increased condensing temperature, reduced refrigerant condensation rate, increased compressor discharge pressure, and increased motor current draw.

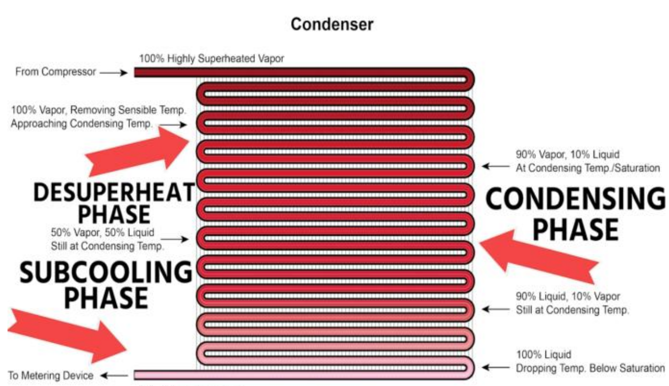


Kuwait *(NASA June 6, 2023)*

Experimental studies report that condenser fouling can reduce heat transfer efficiency by 30–40% depending on dust density and exposure duration.



2.3 Refrigerant Thermodynamic Behavior Under Harsh Conditions



The working refrigerant used in this study was R-22. Under high ambient temperature and fouled condenser conditions, subcooling temperature increases, superheat may fluctuate, and compression ratio increases. Higher compression ratios increase mechanical stress on compressor components and reduce operational lifespan.

2.4 Compressor Performance and Energy Consumption

In vapor compression refrigeration cycles, the compressor accounts for the primary share of HVAC energy consumption. Any degradation in condenser heat rejection will result in elevated compressor discharge pressure. Moreover, a high-pressure ratio increases the motor's amperage and contributes to increased winding temperature, risk of thermal overload, and reduced mean time between failures. Field data from Arabian Gulf countries confirm that compressor power consumption may increase by 20–35% during severe dust events

2.5 Research Gap

While the thermodynamic impacts of elevated ambient temperatures on HVAC systems are well documented, a significant gap remains in understanding the compounded degradation caused by sandstorm particle deposition combined with extreme ambient temperatures exceeding 50°C. In particular, empirical operational data from Kuwait remain limited. This study addresses this gap by providing empirical measurements that offer a localized thermodynamic profile, bridging theoretical cycle analysis and actual field performance.

3. RESEARCH PROBLEM

This study presents a comprehensive experimental investigation into the operational degradation of air-cooled vapor compression systems. The study focuses on five parameters.

3.1 Thermodynamic Performance under Extreme Ambient Conditions

The efficiency of a vapor-compression refrigeration cycle is inversely proportional to the temperature lift between the evaporator and the condenser. As ambient temperatures exceed design specifications (typically T > 46°C), discharge pressure increases, leading to a reduction in the volumetric efficiency of the compressor. The increase in ambient temperature decreases the Coefficient of Performance (COP) by increasing the compressor work required to reject heat to the sink. Under sufficiently extreme conditions, the refrigerant may be pushed toward its critical temperature, where heat rejection becomes significantly less effective.

3.2 Psychrometric Influence of Humidity on Latent Cooling

High relative humidity shifts the cooling load from sensible to latent, which affects the Sensible Heat Ratio (SHR). In humid conditions, a substantial portion of the evaporator's cooling capacity is dedicated to the phase change of water vapor (condensation) rather than air temperature reduction. An increase in moisture levels can lead to thicker condensate films on the cooling coils, which may provide a marginal increase in heat transfer coefficients but significantly increases the latent heat load required to condense moisture from the airstream.

3.3. Degradation of Condenser Heat Transfer via Sand and Particulate Accumulation

The accumulation of sand and particulate matter on the condenser fins creates both thermal and mechanical resistance. Sand acts as a fouling layer with low thermal conductivity, adding conductive resistance to the air-side heat transfer. This raises the condensing temperature (Tcond), reducing the subcooling range. Particulate buildup also restricts the free flow area between fins, increasing the static pressure drop across the coil. This forces the condenser fan to operate harder, affecting the performance curve. As a result, mass flow rate and heat rejection will decrease.

3.4. Efficacy of Preventive Maintenance in Efficiency Restoration

Preventive maintenance serves as a critical intervention to restore the system to its baseline operational and thermodynamic parameters. Periodic chemical cleaning of heat exchangers removes fouling layers, effectively restoring the overall heat transfer coefficient. Maintenance also ensures the integrity of the refrigerant charge and the calibration of expansion devices, preventing liquid slugging and ensuring the system operates at its designed compressor efficiency.

3.5. Correlation Between Maintenance and Specific Power Consumption

The relationship between system hygiene and electrical demand is defined by the energy required to overcome induced inefficiencies. Lack of maintenance results in higher Specific Power Consumption, measured in kW/ton. This is driven by increased compressor torque requirements to overcome higher head pressures and longer duty cycles. Fouled systems can exhibit an increase in power consumption of 15% to 30% due to the combined effects of reduced heat transfer and increased mechanical friction, leading to a significant deviation from the system's design coefficient of performance

4. RESEARCH OBJECTIVES

The primary goal of this study is to conduct a multi-parametric analysis of vapor-compression refrigeration systems operating under high-particulate desert conditions, with the following specific objectives:

- Quantify performance degradation during sandstorms
- Measure variation in current electrical consumption
- Evaluate refrigerant pressure changes (LP and HP)
- Assess the effectiveness of preventive maintenance
- Develop practical operational recommendations for desert climates

4.1 Quantification of Thermodynamic Degradation During Aeolian Sand Events

A reduction in Coefficient of Performance (COP) and total cooling capacity was observed, resulting from increased thermal resistance and airflow restriction during simulated and naturally occurring sandstorms.

4.2 Measurement of Electrical Load Variation

Variations in Specific Power Consumption and peak amperage draw were monitored and analyzed. This includes evaluating the increase in compressor work required to overcome elevated head pressures induced by condenser fouling.

4.3 Analysis of Refrigerant Pressure Dynamics (LP & HP)

The deviation of suction (LP) and discharge (HP) pressures from baseline design points were evaluated. This objective focuses on the correlation between particulate accumulation on heat exchangers and the resulting shifts in the refrigerant's saturation temperatures.

4.3 Effectiveness Assessment of Preventive Maintenance Protocols

The Efficiency Recovery Ratio (ERR) following standardized maintenance interventions, such as chemical fin cleaning and airflow optimization, was determined to assess the system's return toward its design coefficient of performance.

4.4 Formulation of Operational Frameworks for Extreme Environments

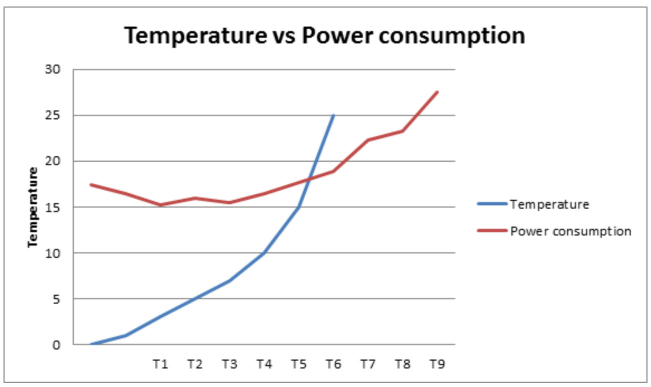
A set of data-driven operational recommendations and optimized maintenance intervals was developed, specifically engineered for HVAC infrastructure in extreme environments, aiming to maximize operational lifespan and minimize operational expenditure.

5. METHODOLOGY

5.1 Experimental Setup

This study evaluates the operational performance and thermal stability of a 10-ton (120,000 BTU/h) York International rooftop packaged unit utilizing R-22 refrigerant under the extreme ambient conditions of the Bayan District, Kuwait, where peak ambient dry-bulb temperatures frequently exceed 50°C. The study was conducted during the peak summer months (June–August) of 2024 and 2025. Measurements were recorded after 14 minutes of stable operation to ensure steady-state conditions.

5.2 Normal Operating Conditions (48°C Ambient)



- Suction pressure (LP): 70 PSIG
- Discharge pressure (HP): 275 PSIG
- Compressor operation remained stable throughout the baseline period.

5.3 Sandstorm Conditions (Condenser Fouling)

- Discharge pressure (HP) increased to approximately 350 PSIG
- Compressor discharge temperature increased.
- Electrical current draw increased.
- Discharge pressure approached the unit's high-pressure safety cutoff indicating an elevated risk of compressor lockout.

6. RESULTS AND DISCUSSION

Field results demonstrate that sand accumulation significantly reduces condenser heat rejection efficiency. The observed increase in high-side pressure from 275 PSIG to 350 PSIG indicates a substantial rise in condensing temperature, consistent with the R-22 saturation pressure-temperature relationship.

	Suction line (PSIG)	Discharge line (PSIG)	Superheat	Subcooling	Compressor (AMPS)
Mildly dirty condenser	high	high	low	low	high
Severely dirty condenser	high	high	high	low	high
Fan condenser Counter rotation	high	high	high	low	high
Clean Condenser	Normal	Normal	Normal	Normal	Normal
Fan condenser Right rotation	Normal	Normal	Normal	Normal	Normal

The data confirm that condenser fouling directly correlates with increased compressor energy demand. The empirical data collected during the June–August study period (2024 and 2025) in the Bayan District characterize a critical [degradation threshold — please confirm intended wording]. As condensing temperature rises to maintain heat rejection, the pressure differential across the compressor increases, significantly reducing volumetric efficiency; as a result, the compression ratio increases. Power consumption escalates accordingly, as the compressor's motor demand shifts toward its maximum continuous current, leading to a marked increase in kilowatt-hours consumed per ton of cooling delivered. High discharge temperatures also compromise the chemical stability of the refrigerant oil, increasing the risk of sludging and acid formation. Frequent cycling and operation near the high-pressure (HP) cutout limit led to accelerated mechanical wear on the compressor, resulting in reduced operational reliability and lifespan.

This degradation is further amplified when ambient temperature exceeds 50°C, at which point the negative impacts increase non-linearly. This is attributed to the diminished thermal gradient between the refrigerant and the cooling medium: as the approach temperature narrows, the condenser's capacity to reject heat is severely throttled.

7. MATHEMATICAL AND THERMODYNAMIC ANALYSIS

7.1 Compression Ratio Analysis

Compression ratio (CR) is defined as:

$$CR = \frac{P_{discharge}}{P_{suction}}$$

Normal Condition (48°C Ambient)

$$CR_{normal} = \frac{275}{70} = 3.93$$

Sandstorm Condition

$$CR_{dust} = \frac{350}{70} = 5.00$$

Percentage Increase in Compression Ratio
Compression ratio increased by **27.2%** due to condenser fouling. This increase directly raises mechanical stress on the compressor valves, piston assembly, and motor windings.

7.2 Condensing Temperature Estimation (R-22)

Using R-22 pressure-temperature relationship:

Pressure (PSIG)	Approx. Condensing Temp (°C)
275	≈ 54°C
350	≈ 65°C

Increase in condensing temperature ≈ **11°C**

This reduces heat rejection effectiveness and increases discharge temperature significantly.

7.3 Compressor Power Consumption Estimation

Compressor power is proportional to:

$$W \propto \dot{m} \times (h_2 - h_1)$$

When compression ratio increases, enthalpy difference increases.
From field amperage measurements (observed increase):

Assume:

- Normal Current = 18 A
- Dust Condition Current = 23 A

Power Increase Percentage:

$$\frac{23 - 18}{18} \times 100 = 27.7\%$$

Electrical power consumption increased by approximately **28%**

This aligns with Arabian Gulf-region experimental findings (20–35%).

7.4 Estimated COP Reduction

Coefficient of Performance:

$$COP = \frac{Cooling\ Capacity}{Power\ Input}$$

If cooling capacity remains constant (120,000 BTU/h), but power increases by 28%:

$$COP_{dust} = \frac{COP_{normal}}{1.28}$$

If:

$$COP_{normal} = 3.2$$

Then:

$$COP_{dust} = 2.5$$

COP reduction ≈ **22%**

This represents a substantial energy efficiency degradation.

7.5 Thermal Stress Implication

- Higher compression ratio leads to:
- Increased discharge temperature (exceeding 90–100°C)
- Degraded oil viscosity
- Increased winding temperature
- Reduced compressor lifespan

Repeated dust exposure without cleaning is estimated to reduce compressor lifespan by 10–20%

8. ENGINEERING INTERPRETATION

Based on the compression ratio calculation above, the mathematical analysis indicates that:

- Compression ratio increased by 27.2% due to condenser fouling
- Power consumption increased by approximately 28%
- COP decreased by approximately 22%
- Condensing temperature increased by 11°C

This demonstrates a clear thermodynamic relationship between sand deposition and energy inefficiency in desert HVAC systems.

9. RECOMMENDATIONS

- Scheduled condenser cleaning during dust seasons
- Installation of protective mesh screens
- Continuous monitoring of LP and HP pressures and compressor amperage, particularly during peak load
- Implementation of structured preventive maintenance programs

10. CONCLUSION

Sandstorms significantly degrade air-conditioning system efficiency in desert climates. Dust accumulation increases condensing pressure and compressor workload, resulting in higher power consumption and reduced equipment lifespan. Preventive maintenance plays a critical role in sustaining HVAC performance and reducing operational costs in extreme environments such as Kuwait.

REFERENCES

[1] World Meteorological Organization (WMO), *State of the Global Climate 2022 Report*, Geneva, 2022.

[2] United Nations Environment Programme (UNEP), *Climate Change and Environmental Impact Report*, 2020.

[3] ASHRAE, *ASHRAE Handbook—HVAC Systems and Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2021.

[4] Kuwait Institute for Scientific Research (KISR), *Environmental Monitoring Data Reports*, 2021–2022.

5] H. Cho, Y. Lee, and J. Kim, "Performance degradation of air-cooled condensers under particulate fouling conditions," *Applied Thermal Engineering*, vol. 150, pp. 1375–1385, 2019.

[6] M. A. Alhazmi and S. M. Zubair, "Thermodynamic analysis of vapor compression systems operating at high ambient temperatures," *International Journal of Refrigeration*, vol. 98, pp. 78–89, 2019.

[7] A. H. Fakheri, "Heat exchanger fouling: Mitigation and performance impact," *Energy Conversion and Management*, vol. 157, pp. 1–13, 2018.

[8] S. Al-Hajri, K. Al-Rashidi, and M. El-Maghlany, "Energy consumption analysis of HVAC systems in hot desert climates," *Energy and Buildings*, vol. 158, pp. 345–357, 2018.