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Topical Article

The Impact of AI in Prescriptive Maintenance for Chillers and Heat Pumps

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Miguel Nájera García, Carrier South Europe, Spain

AI-driven prescriptive maintenance is transforming the way HVAC systems are managed. By integrating real-time monitoring, predictive analytics, and automated decision-making, this approach delivers measurable gains in performance, sustainability, and reliability. No longer experimental, AI is becoming a trusted ally in the pursuit of decarbonization and operational excellence. For facilities aiming to meet energy, environmental, and financial goals, prescriptive maintenance offers a strategic pathway that aligns smart technology with long-term success.

Introduction

The HVAC industry is undergoing a significant technological transformation, driven by growing demands for energy efficiency, decarbonization, and operational resilience. Traditional maintenance strategies, reactive and preventive, often fall short in addressing the dynamic needs of today's complex mechanical systems. In response, advanced data-driven methodologies are emerging, with prescriptive maintenance standing out as a practical and highly effective solution for chillers and heat pumps, the central components of hydronic HVAC systems.

Prescriptive maintenance combines real-time system data, advanced analytics, and simulation models to forecast failures and recommend specific, actionable interventions. This paper outlines the key mechanisms behind prescriptive maintenance in commercial

HVAC systems, focusing on chillers and heat pumps deployed in critical sectors such as healthcare, office real estate, and hospitality.

Overview of Prescriptive Maintenance

Prescriptive maintenance solutions use high-frequency operational data collected through IoT-enabled components, Building Management Systems (BMS), and dedicated sensors. Through the application of machine learning algorithms and thermodynamic modeling, these platforms identify deviations from expected behavior, perform root cause analysis, and generate prioritized maintenance recommendations. Key capabilities include:

- **Continuous monitoring** using temperature, pressure, and energy sensors.
- **Anomaly detection** through multivariate statistical analysis and pattern recognition.
- **Hybrid digital twins** for predictive simulations and system optimization.
- **Decision support** through cost-risk-based maintenance recommendations.

This approach enhances system reliability, lowers lifecycle costs, and enables predictive resource allocation. As AI models are further integrated, facility teams gain access to automated insights that can be acted upon immediately, reducing the lag between detection and resolution.

System Connectivity: How it Works

For AI-enabled prescriptive maintenance to function effectively, the chiller must be integrated into the building's digital infrastructure. This involves both physical and logical connections that allow the chiller to communicate with supervisory control systems and remote analytics platforms.

Logically, the chiller's data points are tagged and normalized to align with semantic data models, ensuring consistent interpretation across various software tools. This structure enables scalable analytics and seamless integration with AI dashboards, visualization tools, and mobile maintenance applications. Key steps in the operational process include:

- **Asset connection** to IoT infrastructure.
- **Data acquisition and trending** via IoT platforms.
- **Remote monitoring** through a centralized command center, with critical alarm tracking and connectivity checks.
- **AI analysis**, using predefined algorithms to detect opportunities and risks, interpreted by technical experts.
- **Customized reporting**, including health diagnostics or component-specific alerts.

The system identifies early indicators of potential issues (e.g., abnormal refrigerant temperatures, pressure anomalies, waterflow irregularities), interprets the data to determine degradation levels, and assesses potential impacts such as increased energy

consumption or component stress. Based on this, tailored recommendations are generated (e.g., preventive maintenance, upgrades, or replacements).

Technical Applications for Chillers & Heat Pumps

AI enables a wide range of applications that improve the long-term performance of HVAC equipment. Among the most impactful use cases are:

1. **Health Diagnostics & Fault Detection**
   AI-powered diagnostics interpret real-time performance data to detect early signs of system degradation. Predefined algorithms classify symptoms and recommend targeted corrective actions, reducing downtime and improving reliability.

2. **Refrigerant Leak Characterization**
   Continuous monitoring of critical parameters enables early detection of refrigerant leaks. Subtle deviations in pressure, superheat, or temperature differentials trigger alerts before major performance losses or environmental risks occur.

3. **EER & COP Tracking**
   Performance degradation is quantified using a computed index based on deviations from baseline Energy Efficiency Ratio (EER) or Coefficient of Performance (COP). If the index drops below acceptable thresholds, the AI system isolates the root cause and suggests corrective actions. Such metrics are essential for facilities operating under Energy Performance Contracts (EPCs), where maintaining efficiency impacts compliance and financial results.

4. **System Upgrade Identification**
   AI insights guide decision-making around system retrofits. By analyzing runtime patterns, seasonal loads, and part-load efficiencies, facility managers can prioritize components offering the highest upgrade potential and quantify energy savings through simulations. This also supports decarbonization by identifying interventions that reduce emissions and improve operational sustainability.

5. **Incentives Compliance**
   In many European countries, financial incentives are available for energy-efficient HVAC upgrades. AI monitoring systems play a key role in quantifying and validating actual energy savings, ensuring compliance, and unlocking funding opportunities.

Examples of Digital Services

This article includes examples of various applications that show the potential of these systems in maintenance tasks and decision-making.

A. Condenser Health in Air-Cooled Chillers

Application: Hotel
Model: 30RBP550R / Scroll Compressors / Air-Cooled / 2 circuits
Evaporator: Direct expansion brazed-plate heat exchanger
Condenser: All-aluminium micro-channel coils (MCHE)
Refrigerant: R-32
Observations & findings:
The Condenser Refrigerant - Air Temperature Difference (also known as Approach Temperature) in air-cooled chillers typically ranges between 18°F to 27°F. This is the temperature difference between the saturated condensing temperature (refrigerant temperature in the condenser) and the ambient air temperature entering the condenser. A higher approach means the chiller is working harder (less efficient).

Figure 1: Approach Temperature for Air-Cooled Chiller

The condenser refrigerant-air temperature difference is higher than normal; this indicates condenser fouling that will impact the efficiency of the unit, but also minimize the life expectancy.

The AI model includes all the data libraries needed to calculate the level of energy waste that the unit is having, which will help to quantify the ROI (Return On Investment) of the possible actions to be taken. In this case, the unit is having 27% higher energy consumption than expected.

Figure 2: Monthly Energy Waste

Recommendations:
Based on the insights provided by the monitoring system, the recommendations in this case include planning the coil cleaning as soon as possible and analyzing the possibility of making a coil treatment due to the exceptionally dusty environment.

B. Refrigerant Leak

Application: Hospital
Model: 30KAV-1100 / Variable Speed Screw Compressors / Air-Cooled / 2 circuits
Evaporator: Flooded shell and tube heat exchanger
Condenser: Micro Channel Heat Exchanger
Refrigerant: R-1234ze
Observations & findings:
AI monitors the main parameters on refrigerant circuits to detect deviations from normal operating ranges based on load and ambient conditions. The expansion valve regulates refrigerant flow into the evaporator. If refrigerant levels are low, the valve may remain more open or show erratic movement to maintain proper superheat.

Figure 3: Expansion valve position

Other key parameters include the suction and discharge pressures, which represent the pressures on the low- and high-pressure sides of the refrigeration circuit. A drop in suction pressure is often one of the first signs of a refrigerant leak, indicating a reduced refrigerant charge. Discharge pressure may also fluctuate abnormally as the system tries to compensate. Also, the temperature difference across the evaporator (between inlet and outlet water or air) may decrease if less refrigerant is available to absorb heat.

Figure 4: Suction Saturated Temperature

Other variables that are analyzed are the evaporator pressure and approach, discharge superheat, condenser approach, or the evaporator water temperature difference. All together will help the user to determine if there is a real refrigerant leak in the unit.

The suction saturated temperature of circuit B is lower than normal; the evaporator approach and the discharge superheat of circuit B is higher than normal. The condenser air-refrigeration temperature difference of circuit B is decreasing. All these conditions indicate that circuit B of this unit has a refrigerant leakage issue with a high severity index.

Recommendations:
Refrigerant leaks may cause the system to cycle more frequently or run for longer periods to maintain the desired temperature setpoints. In this case, the fact that the unit serves a hospital makes it especially important that the leak is repaired in the shortest possible time.

C. VFD Fan Upgrade

Application: Industry
Model: 30XA802 / Screw Compressors / Air-Cooled / 2 circuits
Evaporator: Flooded Multi-pipe Type
Condenser: Micro Channel Heat Exchanger
Refrigerant: R-134a
Observations & findings:
AI monitoring detected that condenser fans on the air-cooled chiller were running at 100% speed even when ambient temperatures were below 20°C. By modeling energy consumption with VFD modulation, the AI system estimated an 18% reduction in chiller power use, with a projected payback of 18 months for the retrofit.

Figure 5: Fan Staging

Recommendations:
The insight provided by the monitoring system helped the facility manager prioritize the VFD upgrade in the next capital plan, reducing the operating cost and the CO_2 emission of the HVAC system.

Implementation Considerations

Although these monitoring systems are becoming easier to integrate, being installed as standard during unit manufacturing and connected during the start-up, some considerations must be taken when implementing them:

- Data Accuracy and Resolution: Reliable performance requires high-quality sensor data and standardized data formats.
- Workforce Readiness: Staff must be trained to understand diagnostics and execute prescribed actions.
- Cost-Benefit Analysis: Deployment should be guided by clear ROI metrics and KPIs (Key Performance Indicators). It is necessary to quantify the energy and maintenance cost savings that the system has generated.

Quantifiable Benefits

- Downtime Reduction: Unplanned outages reduced by up to 50%.
- Energy Optimization: HVAC energy use decreased by 10–25% through dynamic control.

- Maintenance ROI: Improved labor efficiency and material usage from task prioritization.
- Equipment Longevity: Component life extended by up to 25% via early-stage detection.
- Compliance Enhancement: Improved refrigerant tracking for F-Gas and ESG (Environmental Sustainability Goals) reporting.

Conclusions

AI-driven prescriptive maintenance is transforming the way HVAC systems are managed. By integrating real-time monitoring, predictive analytics, and automated decision-making, this approach delivers measurable gains in performance, sustainability, and reliability.

No longer experimental, AI is becoming a trusted ally in the pursuit of decarbonization and operational excellence. For facilities aiming to meet energy, environmental, and financial goals, prescriptive maintenance offers a strategic pathway that aligns smart technology with long-term success.

Author contact information

Name	Miguel Nájera
Title	Marketing Director Carrier South Europe
Affiliation	Carrier
E-mail address	miguel.najera@carrier.com

References

[1]. Carrier Abound | Digitally Connected Lifecycle Solutions and Services for Diverse Building Portfolios. Carrier Abound | Digitally Connected Lifecycle Solutions and Services for Diverse Building Portfolios

[2]. Carrier | How to Start Your Net Zero Journey Guide

[3]. Internal Case Studies from ABOUND HVAC PERFORMANCE platform