How to Maintain Cooling System Efficiency Over Time

Clayton Penhallegon, Jr., PE
Integrated Services Group
Keynote Speaker

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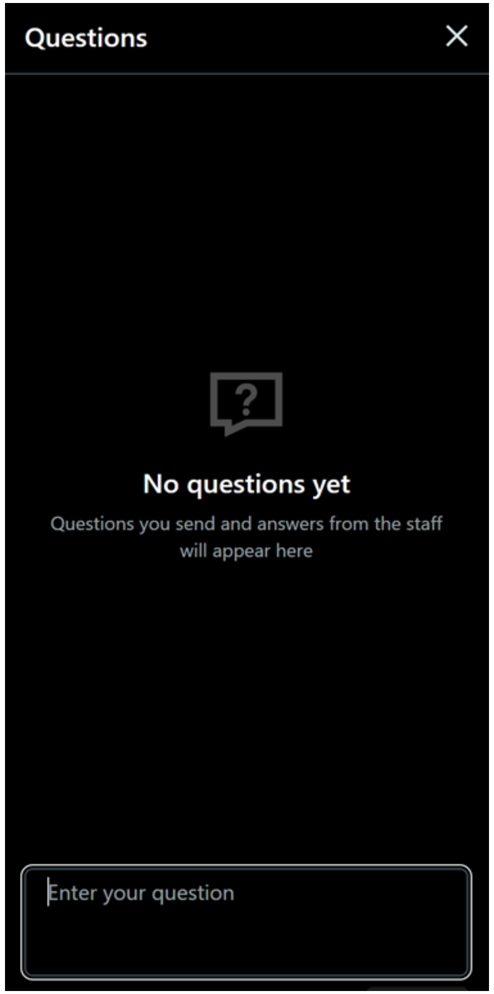
Q&A Format



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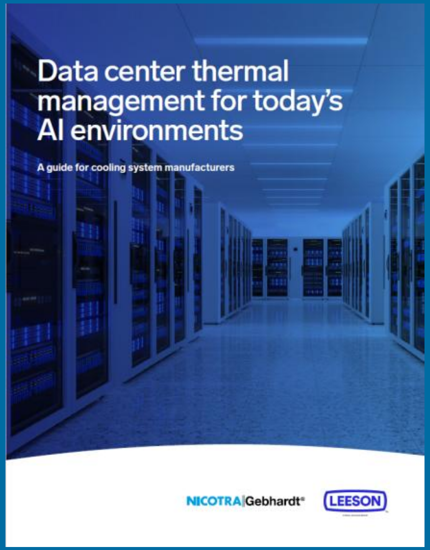
Why Water Systems?
Cooling water systems are one of the most overlooked, yet essential, portions of the manufacturing process. Water systems are almost always:
Engineered very conservatively, using designs and concepts 20, 30, or more years old
Production-critical, but frequently operated within a broad performance envelope
Not controlled to take advantage of seasonal conditions and load reductions



Data center thermal management for today's AI environments
A guide for cooling system manufacturers
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TRACK 1: SYSTEM DESIGN & OPTIMIZATION | TRACK 2: MAINTENANCE, RELIABILITY & PERFORMANCE
TUESDAY, OCT. 13, 2026
WEDNESDAY, OCT. 14, 2026
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32 Alternative Water Strategies for Cooling
38 IMEG Saves 1M Gallons of Water
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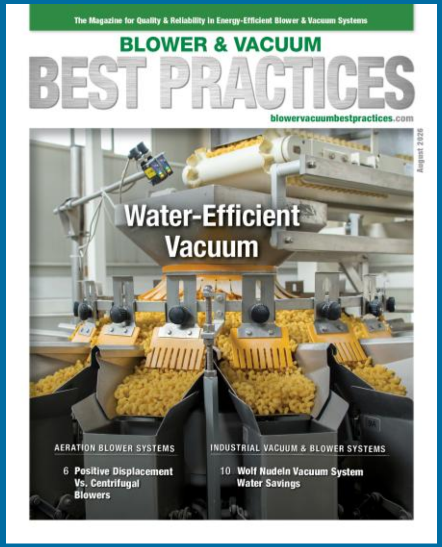
44 Air Gun Safety and OSHA Compliance



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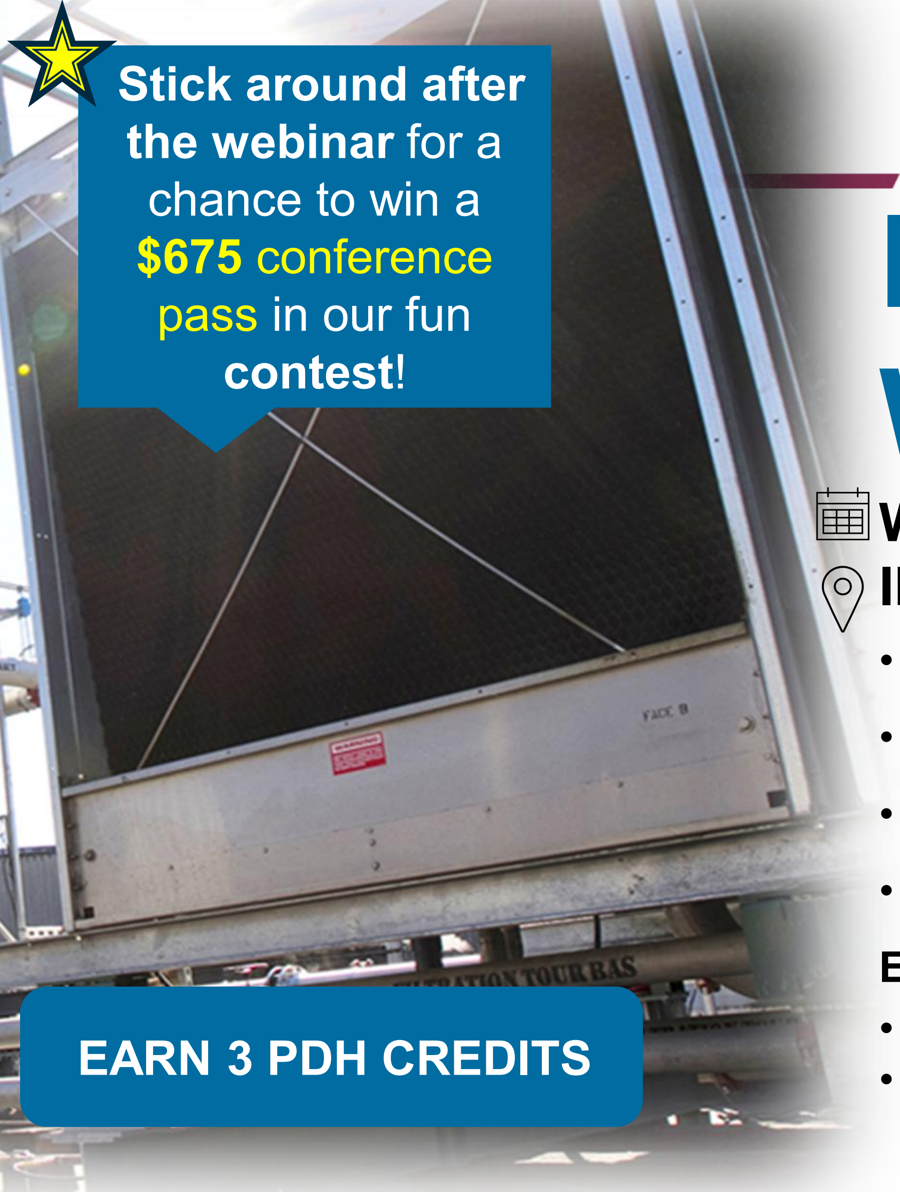
Disclaimer

All materials presented are educational. Each system is unique and must be evaluated on its own merits.



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How to Maintain Cooling System Efficiency Over Time

Introduction

Chiller & Cooling Best Practices® Magazine

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About the Speaker

Clayton Penhallegon, Jr., PE
Integrated Services Group

- Principal Engineer, Integrated Services Group
- >25 years of experience in industrial energy efficiency
- Bachelor of Mechanical Engineering from Georgia Tech
- Registered P.E. for >30 years

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Maintaining Cooling System Efficiency Over Time

August 13, 2026

Clayton Penhallegon
Integrated Services Group

Presentation Outline

- Machine maintenance overview
- Cooling equipment specific maintenance considerations
- Major equipment maintenance
  - Chillers, pumps, heat exchangers
- Minor equipment – gauges, valves, etc.
- Minor tasks that provide multiplier effect savings

Fundamental Purpose of Equipment Maintenance

- The importance of maintenance is widely recognized but the exact financial justification can be unclear
- First purpose is to keep equipment *functional*
  - Unmaintained equipment will fail, sometime catastrophically
  - No one can tell exactly how / when / why for most devices

Fundamental Purpose of Equipment Maintenance

- The importance of maintenance is widely recognized but the exact financial justification can be unclear
- First purpose is to keep equipment *functional*
- Second purpose is to make equipment *work better*
  - Maintained equipment will be more efficient, providing identifiable ROI
  - Minor breakdowns and interruptions can occur on under-maintained equipment, effective maintenance can avoid these unplanned stoppages and the resulting production impacts and costs

Typical Plant Utilities Maintenance Tasks

- Typically planned on mechanical function assumptions, time of operation-based
- Routine maintenance
  - Filter replacements
  - Lubricant level checks & fills
  - Belt inspections & replacements
  - Chiller tube cleaning / plate HX cleaning
  - Tower basin cleaning

Typical Plant Utilities Maintenance Tasks

- Typically planned on mechanical function assumptions, time of operation-based
- Routine maintenance
- Major Equipment maintenance
    - Compressor air-end rebuilds, heat exchanger replacements
    - Pump overhauls or replacements
    - Chiller compressor overhauls, tube replacements
    - Tower fill replacement, basin sealing or replacement

Cooling Efficiency-Enhancing Maintenance

- Cooling equipment has different conditions for evaluation of maintenance
  - Life cycle energy use is several times greater than purchase cost
  - Reliable operation is leveraged through process productivity

Cooling Efficiency-Enhancing Maintenance

- Cooling equipment has different conditions for evaluation of maintenance
  - Life cycle energy use is several times greater than the purchase cost.
  - Reliable operation is leveraged through process productivity
- Preserving rated efficiency creates payback for plant host
- Best Practices use performance-based triggers in addition to time-based
  - Requires adding efficiency monitoring task to activities
  - Good candidate for automation-based monitoring and alerting

Cooling Efficiency Maintenance Triggers

- Direct monitor trigger examples
  - Chiller approach temperatures – evaporator, condenser
  - Pressure loss through filters, strainers

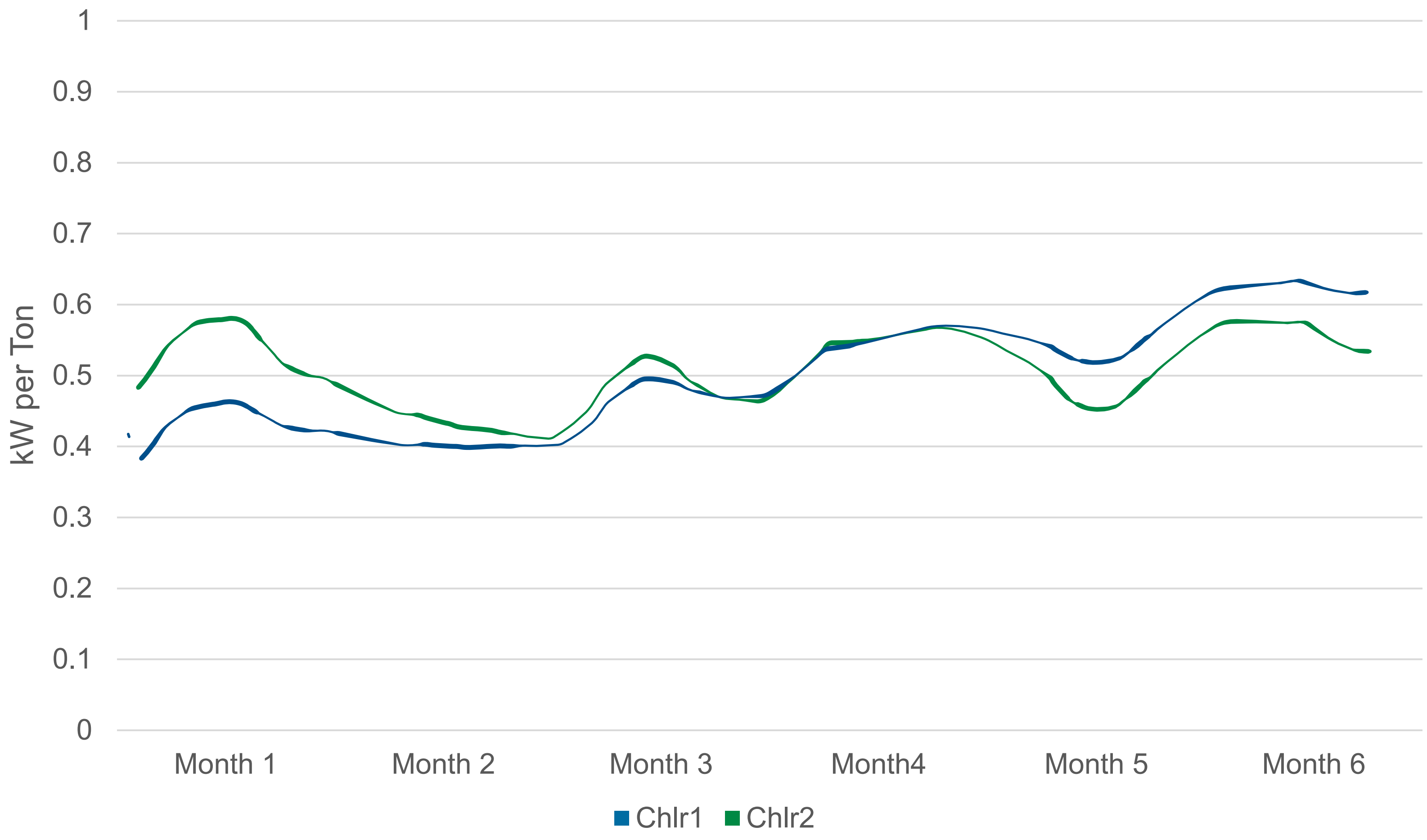
Cooling Efficiency Maintenance Triggers

- Direct monitor trigger examples
- High-level monitor trigger examples
  - Indirect but more informative – supports savings calculations
  - Chiller kW per ton tracking
  - Pump power input
  - Heat exchanger temperature approach at equal conditions

High-Level Trigger Considerations

- These require effective system controls, intelligent application
- Chiller kW per ton tracking
  - Normalize for set point, condensing conditions)
- Pump power input for same conditions
  - A-B rotations, known parallel conditions, etc.
- Heat exchanger temperature approach
  - Conditional analysis depends on actual operating conditions vs. nominal design

Chiller kW per Ton Example & Implications



High-Level Trigger Considerations

- These require effective system controls, intelligent use
- Chiller kW per ton tracking
- Pump power input for same conditions
- Heat exchanger temperature approach
- These and similarly context-sensitive indicators are a great potential application for AI in cooling systems

Chiller Efficiency Details

- Primary controlled variable is condition of the tubes
- Chiller internal (refrigerant side) thermal performance stays uniform
- Properly maintained compressors on centrifugal and screw chillers wear very modestly over time but do periodically require bearings and seals (non-mag bearing units)

Chiller Efficiency Details

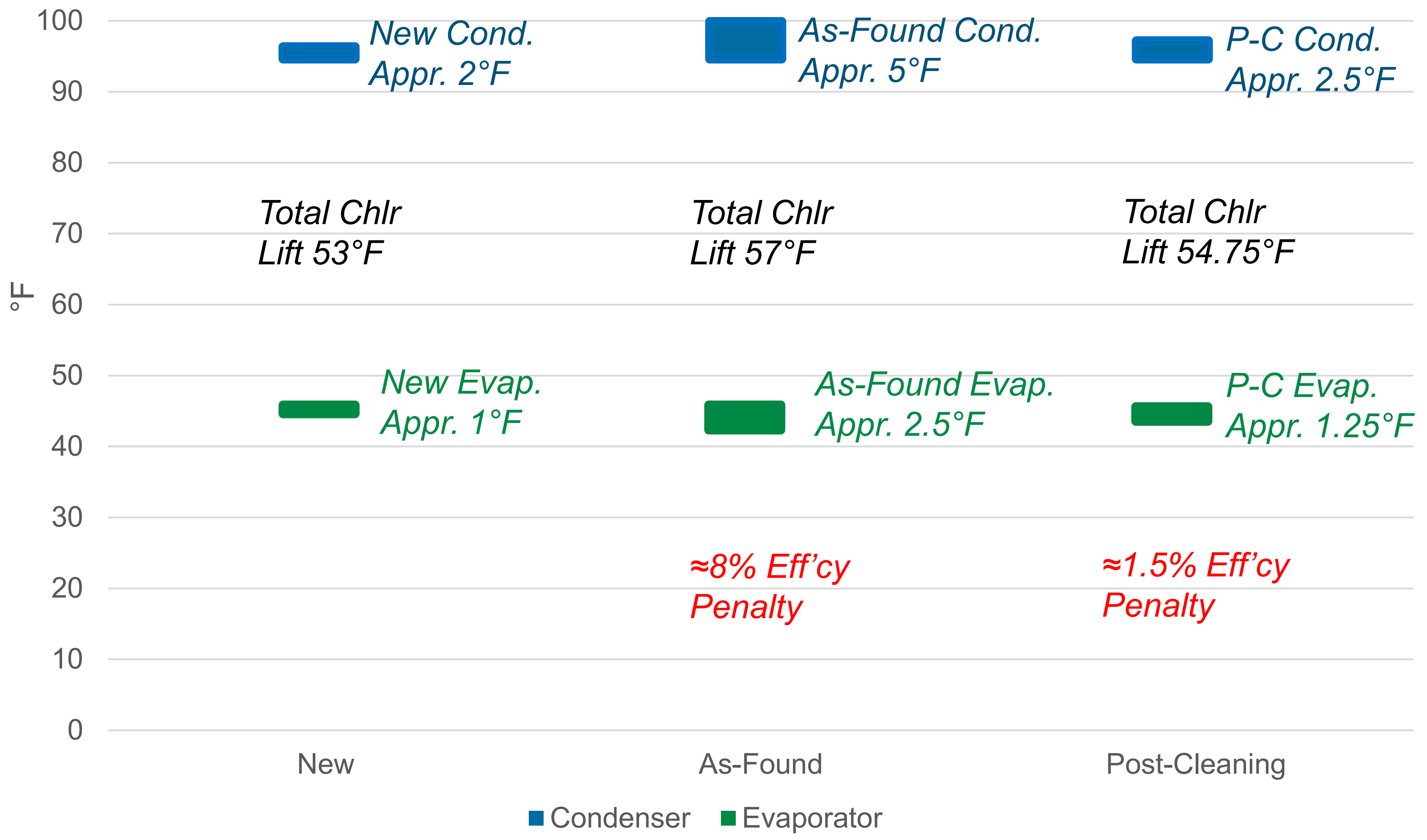
- Primary controlled variable is condition of the tubes
- Chiller internal (refrigerant side) thermal performance stays uniform
- Properly maintained compressors on centrifugal and screw chillers wear very modestly over time but do periodically require bearings and seals (non-mag bearing units)
- Loading directly affects performance, slightly different impacts depending on flow & delta T variations
- Efficiency cost impacts calculated from kW per ton, average loads, annual hours, power cost

Water-Cooled Chiller Efficiency Impact of Tube Cleaning

- Target evaporator approach ≈ 1.0 – 1.5°F
- Target condenser approach ≈ 2.0 – 3.0°F
  (difference between clean system and dirty open loop to tower)
- Approximate efficiency effect ≈ 2% per °F
- Chiller with 3°F evap. appr. and 5°F cond. appr. is ≈8% less efficient than 1.25 / 2.5 machine

  [(3°-1.25°)+(5°-2.5°)] x 2% = 8.5%
- Annual cost penalty @ 10¢ per kWh, 8600 hours per year, nominal 0.6 kW per ton =
  $0.10 X 8600 X 0.6 X 8% = $41.28 per ton
  - Annual savings of $24,800 for 600 tons
  - Tube cleaning cost of ~$12,000, 6 mos. PB

Chiller Tube Cleaning Example & Implications



Pump Efficiency Details

- Usefulness of direct pump power readings depends on consistent conditions
  - Fixed flow loops (suboptimal but common)
  - Pressure-controlled applications better fundamentally and for tracking
- Compare power input over time, in comparable operations
  - A-B rotations in consistent applications
  - Parallel conditions, etc.
- Review inlet conditions for increasing power requirements or declining flows

Pump Inlet Fouling Example

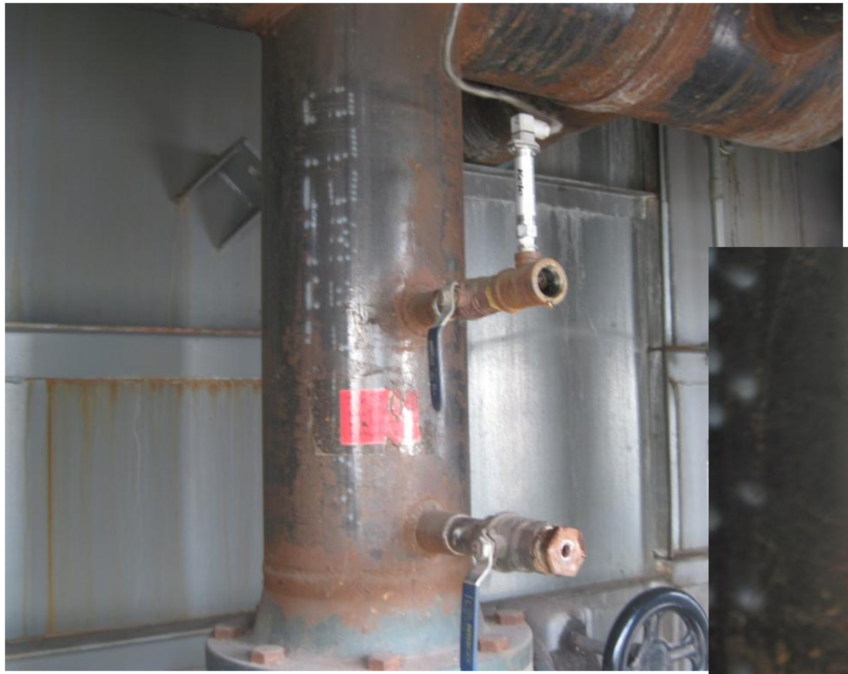
Heat Exchanger Efficiency Details

- Heat exchanger temperature approach highly dependent on flows and actual temperature differences vs. design conditions
- Flow management efficiency strategies significantly affect approach
  - Purposely controlling the temperature to reduce flow on one side changes the performance
  - Track performance and observe trends / changes
  - Conduct periodic controlled tests with defined flows, temperatures
  - Compare results to recorded start-up and post-cleaning data

Minor Component Maintenance

- Minor system components like gauges and valves require maintenance
- Temperature sensors typically less prone to issues but can fail or be damages (resistance devices highly wiring sensitive)
- Tower system pressure gauges and transducers particularly susceptible to pipe plugging and hence false readings
- Direct savings from devices limited, their key value is in supporting power use component analysis (e.g., pumps, etc.)
- Leaking valves, however, can create real costs and be hard to find – fugitive flows, back-spinning pumps, other effects

Pressure Gauge Pipe Plugging Example



Minor Component Critically Support Troubleshooting

- Pressure gauges & sensors, temperature sensors provide important insight into specific system component conditions
  - Individual pumps
  - Heat exchangers
- Prompt, accurate indications assist troubleshooting under pressure
- Value of maintaining minor components trivial compared to benefits of restoring cooling function to process – *what's 1 hour worth?*
- Very easy to overlook, ignore so must be added to maintenance planning system, required for completion

Presentation Outline

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Best Practices References

- Vital Signs: Critical Instrumentation for Cooling System Health, Chiller & Cooling Best Practices magazine, September 2023
- Holistic Controls for Superior Cooling Systems Efficiency Pt. 1, Chiller & Cooling Best Practices magazine, Jan.-Feb. 2024
- Holistic Controls for Superior Cooling Systems Efficiency Pt. 2, Chiller & Cooling Best Practices magazine, June 2024

Maintaining Cooling System Efficiency Over Time

August 13, 2026

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About the Speaker

Dennis Jamora
Regal Rexnord

- Application Engineer, Power Efficiency Solutions at Regal Rexnord
- 30+ years improving motor performance across HVAC, ag, and industrial systems
- MS, Clemson University; MBA, Wright State University
- Engineering expertise plus field experience for today's cooling challenges

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Creating a Better Tomorrow

CHILLER FAN MOTOR BASICS & FUTURE IMPACTS

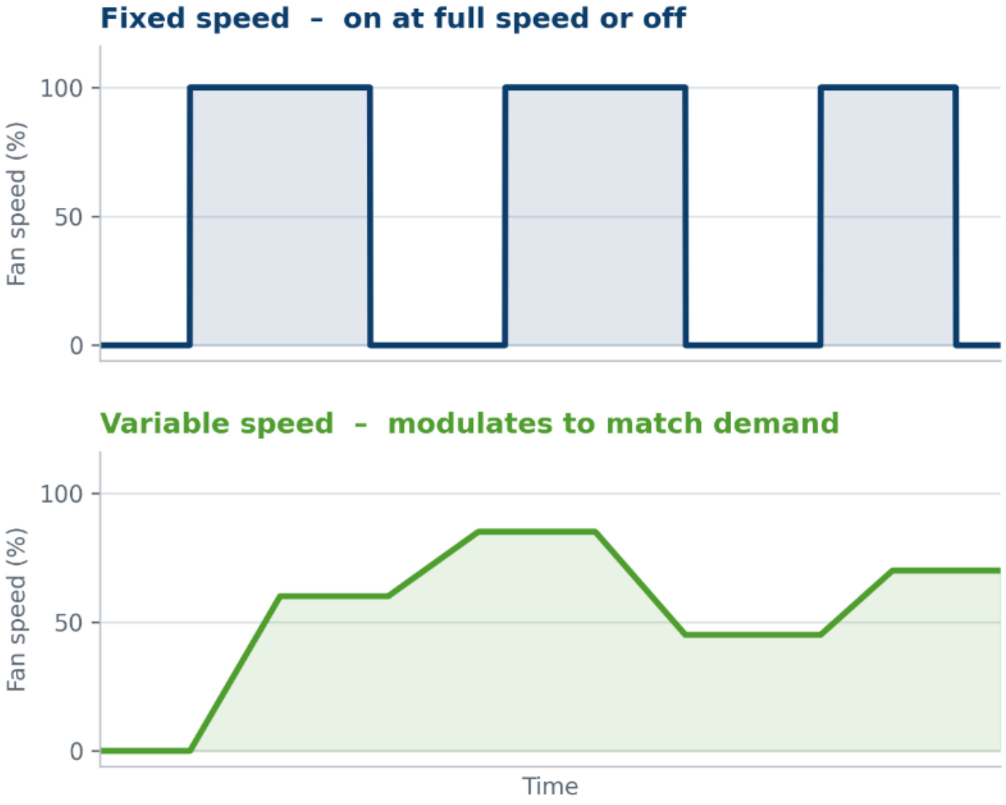
August 13, 2026

Dennis Jamora

Application Engineer

TYPES OF FAN MOTORS FOR AIR-COOLED CHILLERS

- Air-cooled chillers use a fan motor to move air across the condenser coils to reject heat
- Two types of fan motors
    - Fixed speed – fan is either on at full speed or off
    - Variable speed – besides operating at full speed, fan can be commanded to run at a lower speed depending on the airflow needed at the time



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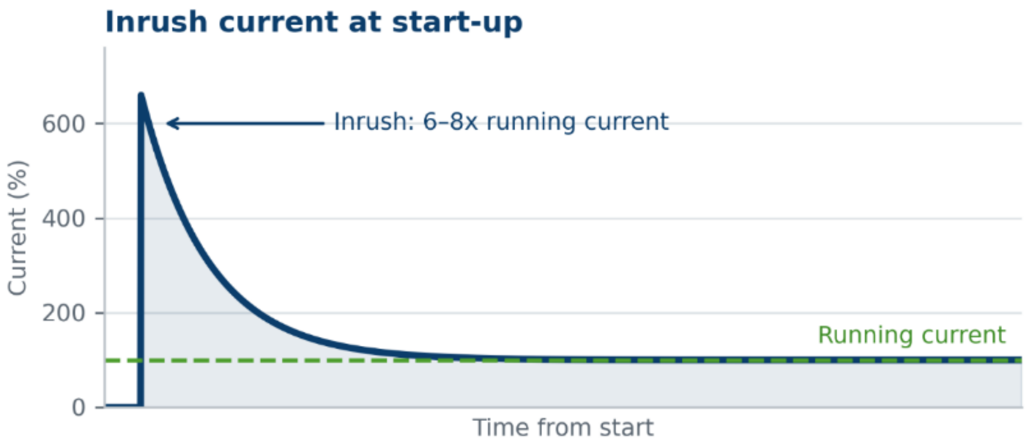
FIXED SPEED AC INDUCTION MOTOR

- Type of motor technology used for a fixed speed application
  - AC Induction motor operating from line voltage
    - Speed is determined by motor design (number of poles) and the frequency of the AC voltage (usually 60 Hz in the USA)
    - Induction motor design is rather simple, and AC induction motors have been produced for over 120 years
    - Motor has very good starting torque – starts immediately when voltage is applied
      - Inrush current can be high when motors start
    - AC induction motors just run – which is a good thing
      - Typical failures are either winding failures or bearing failures
    - Motor efficiency is relatively low
      - The Department of Energy has regulated the efficiency of motors since the mid-1990s; however, air-over motors such as chiller fan motors have been exempt from efficiency regulation until next year – goes into effect June 2027
    - AC induction motors do not have any inherently “smart” features – no feedback on whether the motor is even spinning or what speed it might be going



WHAT CHANGES FOR CHILLER FAN MOTORS IN JUNE 2027?

- The Department of Energy tightened its motor efficiency standards and widened what they cover

How we got here

Jun 2023	Sep 2023	Oct 2023	Jun 1, 2027
DOE issues the direct final rule	Rule takes effect	Compliance date confirmed	Compliance required

What the rule changes

Higher efficiency

Minimum efficiency rises for 100-250 hp induction motors, moving them toward NEMA Super Premium (IE4) levels

Bigger motors covered

New standards extend to larger induction motors, up to 750 hp

Air-over motors covered

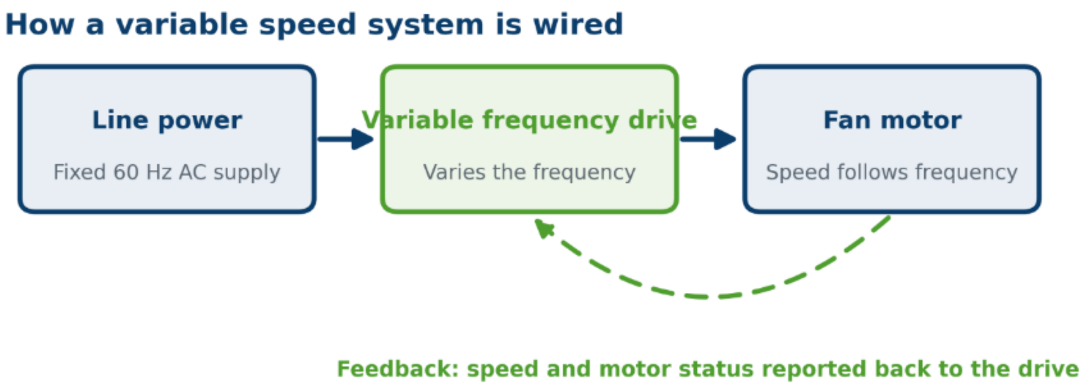
Air-over induction motors get efficiency standards for the first time – the category that includes chiller fan motors

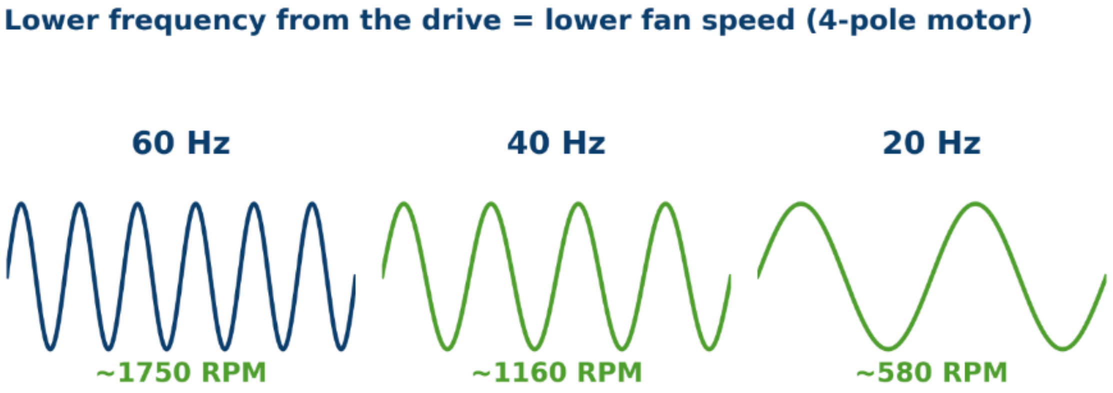
Bottom line: chiller condenser fan motors are air-over motors. Long outside the standards, they must meet DOE efficiency requirements from June 1, 2027

Source: DOE direct final rule, Energy Conservation Standards for Electric Motors, 10 CFR Part 431 (88 FR 36066, June 1, 2023); compliance dates confirmed at 88 FR 72347 (Oct 20, 2023)

VARIABLE SPEED AC INDUCTION MOTOR

- Type of motor technology used for a variable speed application
  - AC Induction motor operating from an inverter or variable frequency drive (VFD)
    - Since motor speed is determined by the number of magnetic poles and the frequency of the AC voltage, a variable frequency drive very simply adjusts the frequency of the voltage signal to adjust the speed of the motor
    - Because of the electronics in a VFD, some feedback on motor operation can be communicated
    - Pairing motors with a VFD (or multiple VFDs) adds complication to the system as well as cost
    - Motor cost also increases as it must be designed and manufactured with extra insulation to survive voltage spikes from the VFD





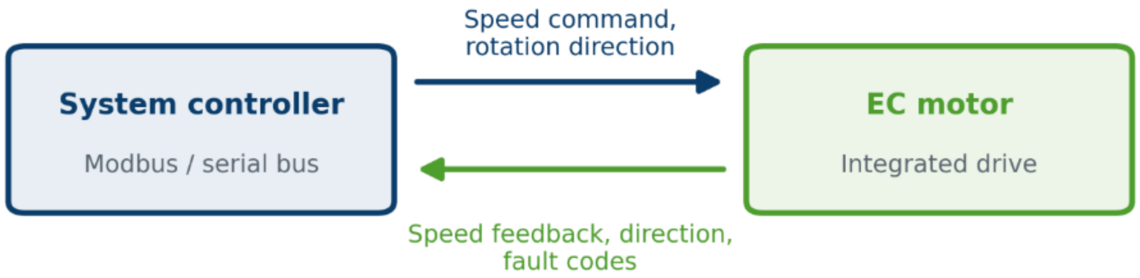
VARIABLE SPEED EC MOTOR

- Type of motor technology used for a variable speed application
  - Electronically Commutated (EC) motors
    - EC motors are typically permanent magnet motors that use a built-in or integrated drive that acts as a VFD for the motor
    - Inputs to an EC motor are three-phase power (like the AC induction motor) and some kind of speed control signal
    - Speed can be commanded with a simple analog, PWM, or digital input – see the input options at right
    - Higher level of communication: Modbus or some kind of serial communication protocol, with each motor addressed on one shared bus
    - Because of the electronics in the integrated drive, an EC motor has the capability of providing feedback to the system controlling the EC fan motors

Speed control input options

Analog voltage	0-10V DC speed command
Analog current	4-20 mA speed command
PWM	Duty cycle sets the speed
Digital inputs	Preset speeds, or enable / on-off
Programmable output	Fault status or speed indication

Two-way communication over Modbus



Each motor has its own address, so one bus serves many motors

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COMPARING THE THREE FAN MOTOR TECHNOLOGIES

- All three move air across the condenser coils – they differ in how speed is controlled, and in what the motor can tell you

	Fixed speed AC induction	Variable speed AC induction + VFD	Variable speed EC motor
Speed control	On at full speed, or off	Drive varies the frequency to set the speed	Analog, PWM, digital or Modbus speed command
Where the drive lives	No drive – runs directly from line voltage	Separate VFD paired with the motor	Drive integrated into the motor
Feedback to the system	None – no indication of speed or even that it is spinning	Some feedback available through the drive electronics	Speed, direction and fault codes reported back
Cost and complexity	Simplest and lowest cost; efficiency relatively low	Added drive cost, extra motor insulation, more complexity	Fewer parts to pair, but motor carries the electronics

DOE efficiency regulation reaches air-over motors such as chiller fan motors in June 2027

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SyMAX-PRO EC Motors

Dennis Jamora

Application Engineer- Power Efficiency Systems (PES)

- 32 years of industry experience
- Expertise in electric motor design and in the use of motors in customer applications
  - Commercial HVAC
  - Agricultural fans
  - General industry products

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Which factor most directly affects chiller efficiency?

A
- Basin water

B
- Tube condition

C
- Ambient noise

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*By entering you are giving permission to announce your name if you are a winner

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How to Maintain Cooling System Efficiency Over Time

Q&A

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Francisco Lara
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