

Pharmaceutical Cooling Plant

AI supervisory control case study - I-P edition

A secondary-pump variable-flow chilled-water plant improved average operating-period efficiency from **0.74 to 0.65 kW/ton** during the AI-control window. The measured change equals a **12.11% plant-efficiency improvement** while keeping commands inside BAS-compatible condenser-water pump and cooling-tower fan bands.

12.11%	37 days	0.74 -> 0.65
Plant efficiency improvement	AI operating window	Average kW/ton, baseline to AI

Executive summary. The AI operating period ran from Sep 1 to Oct 7 for 37 cumulative days. It is compared with valid historical baseline data from Jun 1 to Jul 7. During AI operation, the control strategy adjusted condenser-water pump frequency and cooling-tower fan frequency setpoints. The measured data shows a 12.11% average COP improvement; this I-P version also expresses the same result as a kW/ton reduction.

Measurement window. Baseline operation used 27 valid daily records after excluding days with missing site power data. AI control used 37 daily records. The AI period was hotter and more humid on average than the baseline period, so the weather plots and daily table are included for context.

Scope note. The AI layer optimized condenser-water pump frequency and cooling-tower fan frequency. Chilled-water supply temperature and chilled-water pump frequency were reserved interfaces and were not included in this measured scope.

The following sections provide the site background, AI optimization platform, reinforcement-learning method, representative frequency behavior, efficiency calculation, and daily operating records.

1. Site Background

The site is a pharmaceutical manufacturing facility with a secondary-pump variable-flow chilled-water system. The central plant includes four chillers in a three-duty, one-standby arrangement; four chilled-water pumps; four condenser-water pumps; three air-side chilled-water pumps; and four process-side chilled-water pumps. In normal operation, the plant runs in a one-chiller, one-pump pairing.

Equipment	Brand	I-P specification	Status
Centrifugal chiller	Trane	650 tons cooling; 539 hp input	Running
Chilled-water pump	Grundfos	66 ft head; 40 hp; 1,541 gpm	Running
Condenser-water pump	Xylem	72 ft head; 60 hp; 837 gpm	Running
Cooling tower	BAC	2,201 gpm; 30 hp	Running

The AI optimization platform was built jointly by the project engineering team and the AI controls provider. The platform allows one-click switching between existing group control and AI control. It also supports operator review: AI recommendations can be applied to the group-control setpoints for condenser-water pump frequency and cooling-tower frequency.

Control item	Operating boundary
Condenser-water pump frequency	42 Hz to 50 Hz, constrained by low-flow protection
Cooling-tower fan frequency	22 Hz to 50 Hz, optimized against plant energy and indoor-temperature response
Current optimization scope	Condenser-water pumps and cooling towers
Reserved future interfaces	Chilled-water supply temperature and chilled-water pump frequency
Operating data	BAS operating records, daily system kW/ton, outdoor dry-bulb temperature, and outdoor wet-bulb temperature

The active optimization boundary is cooling-side frequency control. Interfaces for chilled-water supply temperature and chilled-water pump frequency were reserved for future optimization but not included in the measured result.

2. AI Optimization Method

The reinforcement-learning algorithm can adapt to different public and industrial building types, including offices, commercial facilities, hospitals, sports venues, automotive factories, electronics factories, textile factories, data centers, energy stations, and metro stations. The algorithm selects the most relevant optimization surface for the current chilled-water system, such as condenser-water pumps, cooling towers, chiller staging, chilled-water pumps, or air-handling units.

For this project, the cooling-side control loop uses reinforcement learning to choose condenser-water pump and cooling-tower fan commands from current operating state, equipment limits, and feedback. The reward combines overall operating energy and indoor-temperature response, so the policy directly targets plant energy instead of only tracking an intermediate temperature-difference variable.

This matters because conventional tower or pump logic often relies on PID tuning or fixed supply/return temperature-difference targets. Those approaches can be useful, but they have common limitations: PID parameters are hard to tune, early-operation error can be large, feedback can arrive late, and a fixed temperature-difference target may miss lower-energy operating points when weather conditions improve.

- Read current state parameters from the BAS and operating history.
- Check whether load is above the system start threshold.
- Check whether state parameters are inside the configured action range; clamp out-of-range values to the boundary when needed.
- Discretize state parameters, update $Q(s,a)$, and choose pump and tower commands using an epsilon-greedy policy.
- Execute the selected action inside the approved BAS frequency bands.

Cooling-Side Optimization Loop

The supervisory loop below shows how the AI controller reads live BAS state, applies load and control-range checks, updates the Q-learning policy, and writes only bounded condenser-water pump and cooling-tower fan commands back through the BAS.

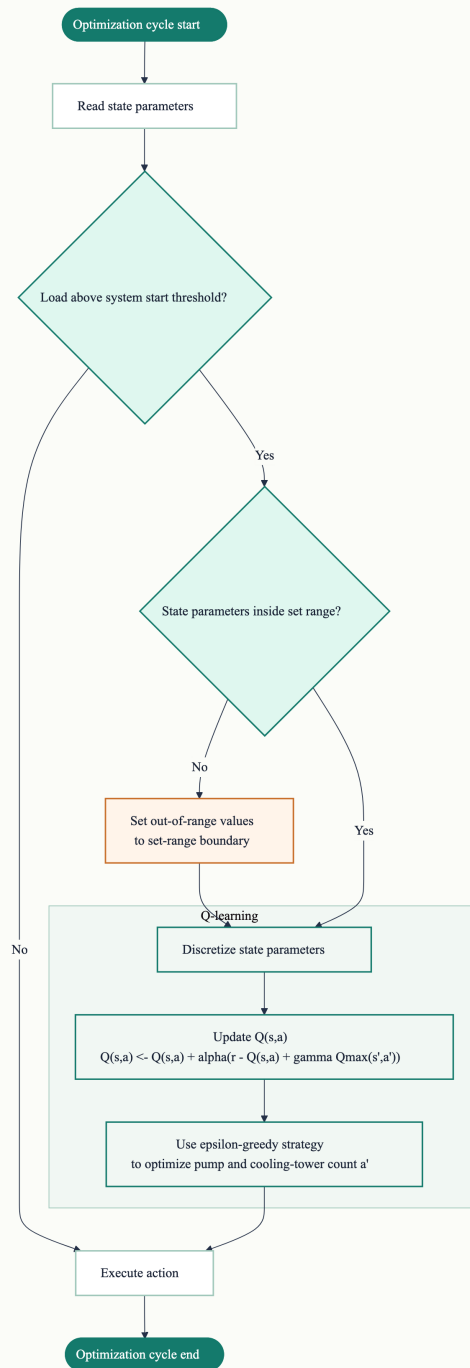


Figure 1. Cooling-water pump and cooling-tower Q-learning optimization strategy.

3. Frequency Behavior

Representative daily frequency behavior is shown before and after AI control. The recreated charts below show the operating pattern in the measured data: baseline operation stayed near fixed frequency, while AI control moved within bounded frequency ranges as load and weather changed.

For condenser-water pumps, baseline operation used approximately fixed speeds around 48 Hz, 47 Hz, and 45 Hz. Under AI control, the condenser-water pumps were allowed to vary from 42 Hz to 50 Hz as long as low-flow protection was not triggered. The reward function considered both total operating energy and indoor-temperature movement.

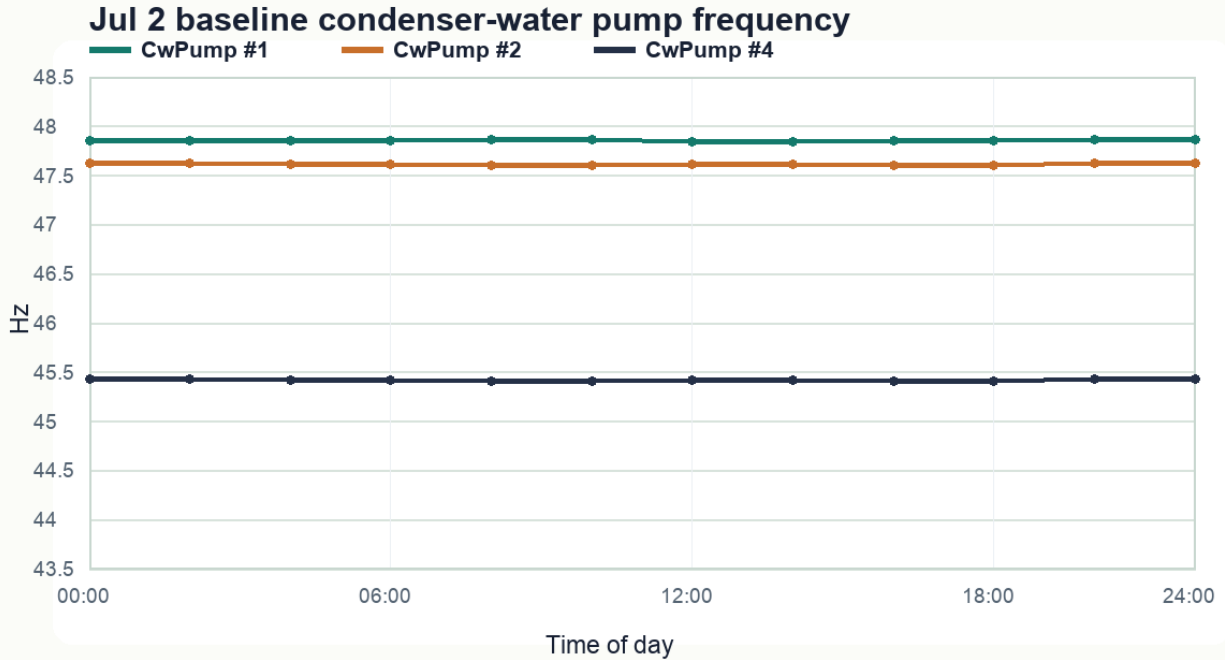


Figure 2. Baseline condenser-water pump frequency on Jul 2 stayed near fixed values around 48 Hz, 47 Hz, and 45 Hz.

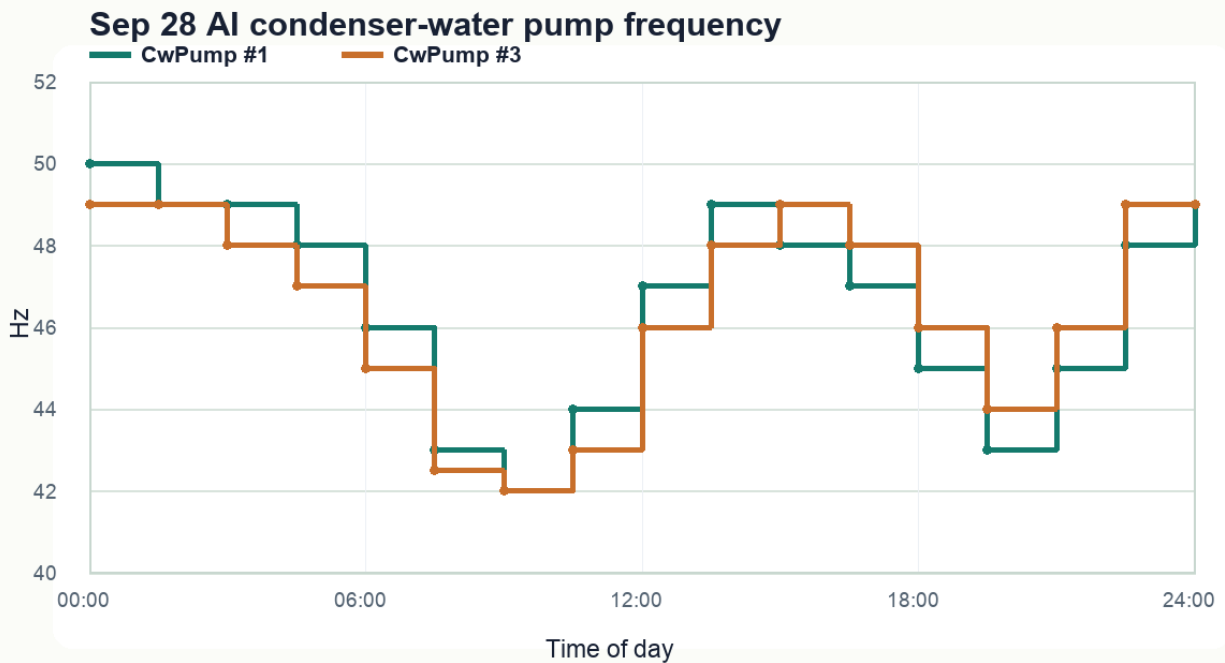


Figure 3. AI condenser-water pump frequency on Sep 28 moved within the 42 Hz to 50 Hz control band.

3. Frequency Behavior (continued)

For cooling-tower fans, baseline operation was close to fixed-frequency operation around 50 Hz, 48 Hz, and 46 Hz. Under AI control, the tower fans were allowed to vary from 22 Hz to 50 Hz. Appropriate tower frequency reduction lowered cooling-tower operating energy by about 30% in the comparison window.

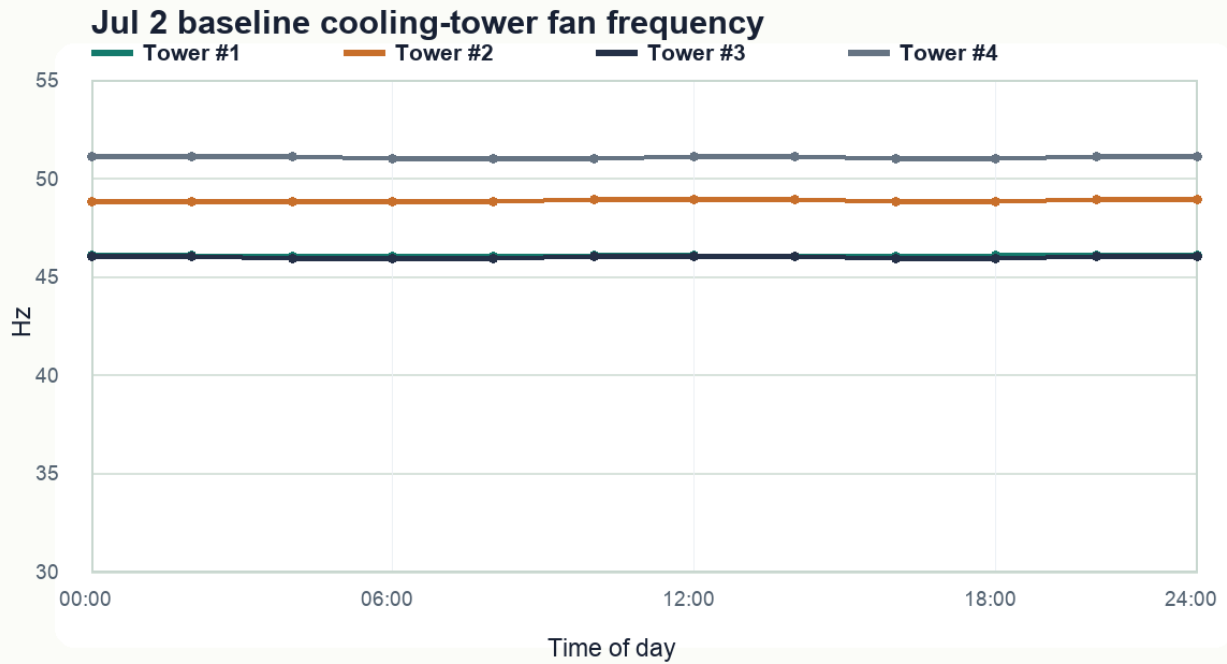


Figure 4. Baseline cooling-tower fans operated near fixed frequency levels.

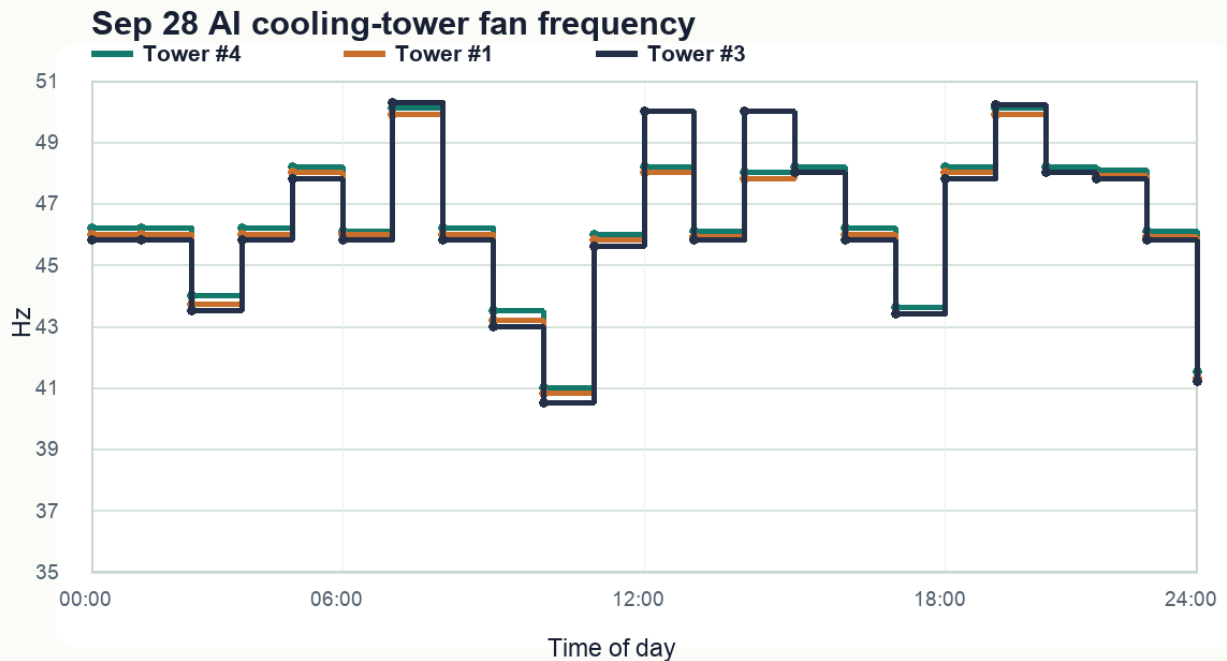


Figure 5. AI cooling-tower fan control stepped down and up through the day; tower running energy fell by about 30% during the comparison window.

4. Plant Efficiency Calculation

Because this measured scope optimized only condenser-water pumps and cooling towers, the calculation is presented as plant operating efficiency rather than whole-building savings. The case calculation reports system COP improvement and also reports kW/ton, where lower values indicate better chilled-water plant efficiency.

The COP averages were 4.75 for baseline operation and 5.41 for AI operation. Using the chilled-water plant conversion kW/ton = 3.516 / COP, those values correspond to approximately 0.74 kW/ton and 0.65 kW/ton.

Metric	Baseline operation	AI control
Valid daily records	27	37
Operating period	Jun 1 to Jul 7	Sep 1 to Oct 7
Average COP	4.75	5.41
Average plant efficiency	0.74 kW/ton	0.65 kW/ton
Average dry-bulb	72.8 °F	78.2 °F
Average wet-bulb	66.8 °F	72.4 °F

Improvement = $(0.74 - 0.65) / 0.74 \times 100\% = 12.11\%$.

I-P reference context

The AI-control period averaged **0.65 kW/ton**, compared with a baseline average of **0.74 kW/ton**. In chilled-water plant reporting, lower kW/ton means less electric input per ton of cooling delivered.

The AI period was warmer on average than the baseline period: 78.2 °F vs 72.8 °F dry-bulb and 72.4 °F vs 66.8 °F wet-bulb. The scatter plots on the next page show the daily operating records used for that comparison.

Energy quantity note. Total kWh and calculated kWh savings are not published in this case file. This PDF therefore reports the verified operating-efficiency improvement and does not infer a missing kWh savings quantity.

5. Daily Operating Data Plots

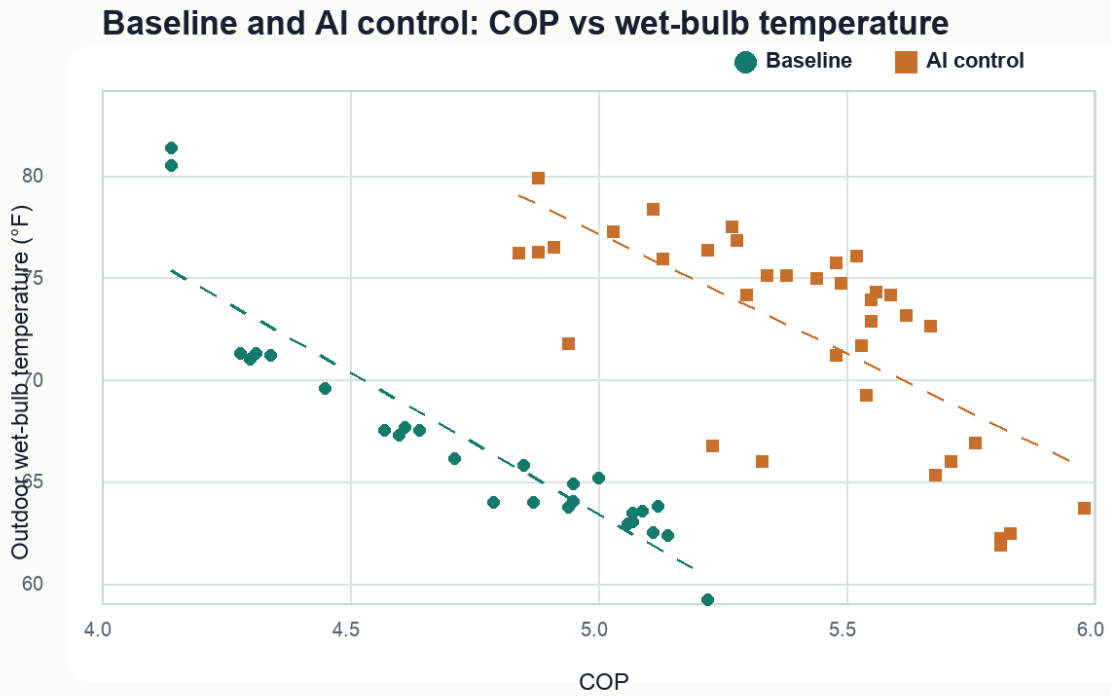


Figure 6. Daily COP vs outdoor wet-bulb temperature, shown in °F, with linear fit lines.

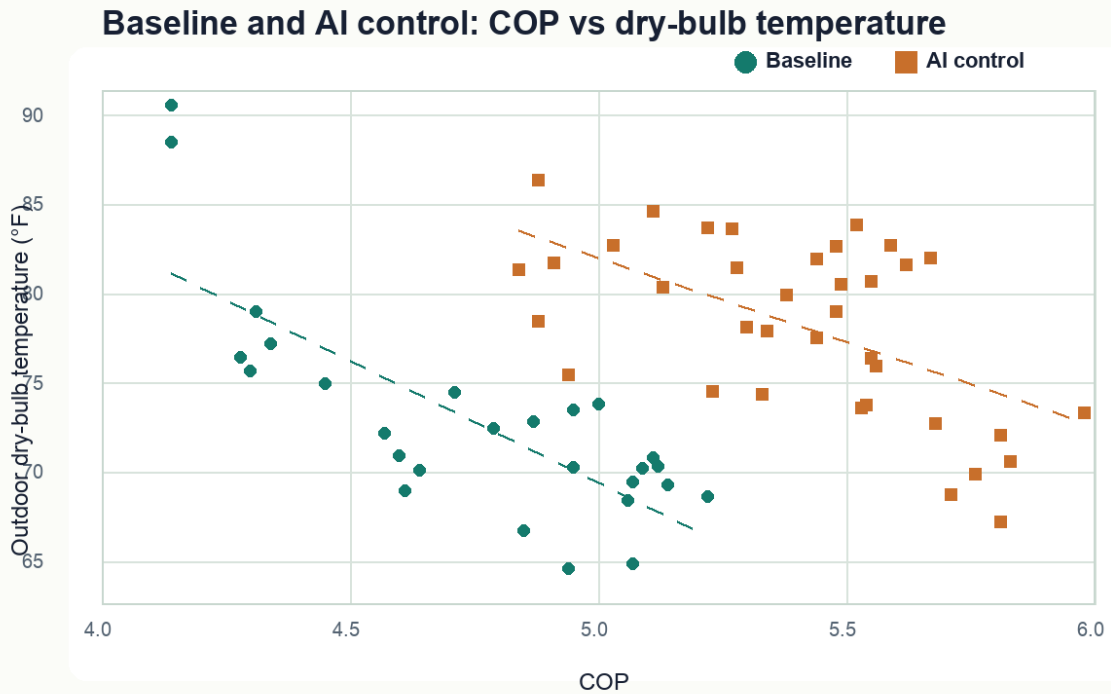


Figure 7. Daily COP vs outdoor dry-bulb temperature, shown in °F, with linear fit lines.

6. Daily Records

The tables below reproduce the daily operating records used in the calculation. Temperatures are shown in °F.

Baseline operation: Jun 1 to Jul 7

Date	COP	kW/ton	Dry-bulb °F	Wet-bulb °F
Jun 1	4.95	0.71	70.3	64.9
Jun 2	4.79	0.73	72.4	64.0
Jun 3	5.22	0.67	68.6	59.2
Jun 8	5.12	0.69	70.3	63.8
Jun 9	5.00	0.70	73.8	65.2
Jun 10	4.95	0.71	73.5	64.0
Jun 11	5.09	0.69	70.2	63.6
Jun 14	5.07	0.69	69.4	63.5
Jun 15	5.11	0.69	70.8	62.5
Jun 16	5.14	0.68	69.3	62.4
Jun 17	5.07	0.69	64.8	63.0
Jun 18	4.85	0.72	66.7	65.8
Jun 19	4.61	0.76	68.9	67.6

Date	COP	kW/ton	Dry-bulb °F	Wet-bulb °F
Jun 20	4.57	0.77	72.2	67.5
Jun 21	4.71	0.75	74.4	66.1
Jun 22	4.87	0.72	72.8	64.0
Jun 23	5.06	0.69	68.4	62.9
Jun 24	4.94	0.71	64.6	63.7
Jun 25	4.64	0.76	70.1	67.5
Jun 26	4.60	0.76	70.9	67.3
Jul 1	4.45	0.79	74.9	69.6
Jul 2	4.30	0.82	75.7	71.0
Jul 3	4.28	0.82	76.4	71.3
Jul 4	4.31	0.82	79.0	71.3
Jul 5	4.34	0.81	77.2	71.2
Jul 6	4.14	0.85	88.5	81.3
Jul 7	4.14	0.85	90.6	80.5

6. Daily Records (continued)

AI control: Sep 1 to Oct 7

Date	COP	kW/ton	Dry-bulb °F	Wet-bulb °F	Date	COP	kW/ton	Dry-bulb °F	Wet-bulb °F
Sep 1	5.48	0.64	79.0	71.2	Sep 19	4.88	0.72	86.3	79.9
Sep 2	5.55	0.63	80.7	72.9	Sep 20	5.13	0.69	80.3	75.9
Sep 3	5.49	0.64	80.5	74.7	Sep 21	5.54	0.63	73.8	69.2
Sep 4	5.27	0.67	83.6	77.5	Sep 22	5.76	0.61	69.9	66.9
Sep 5	5.03	0.70	82.7	77.3	Sep 23	5.71	0.62	68.8	66.0
Sep 6	5.22	0.67	83.7	76.3	Sep 24	5.53	0.64	73.6	71.7
Sep 7	5.48	0.64	82.7	75.7	Sep 25	5.38	0.65	79.9	75.1
Sep 8	5.59	0.63	82.7	74.2	Sep 26	5.30	0.66	78.1	74.2
Sep 9	5.62	0.63	81.6	73.1	Sep 27	4.91	0.72	81.7	76.5
Sep 10	5.67	0.62	82.0	72.6	Sep 28	4.88	0.72	78.4	76.2
Sep 11	5.52	0.64	83.8	76.0	Sep 29	4.84	0.73	81.3	76.2
Sep 12	5.28	0.67	81.5	76.8	Sep 30	4.94	0.71	75.5	71.8
Sep 13	5.34	0.66	77.9	75.1	Oct 1	5.23	0.67	74.5	66.8
Sep 14	5.55	0.63	76.4	73.9	Oct 2	5.98	0.59	73.3	63.7
Sep 15	5.56	0.63	76.0	74.3	Oct 3	5.68	0.62	72.7	65.3
Sep 16	5.44	0.65	77.5	74.9	Oct 4	5.33	0.66	74.4	66.0
Sep 17	5.44	0.65	81.9	75.0	Oct 5	5.81	0.61	72.1	62.2
Sep 18	5.11	0.69	84.6	78.3	Oct 6	5.83	0.60	70.6	62.5
					Oct 7	5.81	0.61	67.2	61.9

7. Case Result and Interpretation

During the 37-day AI-control period, measured average COP improved from 4.75 to 5.41, equivalent to an average plant-efficiency movement from 0.74 to 0.65 kW/ton. The result shows that an AI supervisory layer can improve cooling-side operation while staying compatible with existing BAS operation and operator review.

Result	Value
Average plant-efficiency improvement	12.11%
Average COP	4.75 -> 5.41
Baseline average	0.74 kW/ton
AI-period average	0.65 kW/ton
AI-period best daily efficiency	0.59 kW/ton
AI-period lowest daily COP in daily records	4.84
Optimization scope	Condenser-water pumps and cooling towers
Excluded from measured scope	Chilled-water supply temperature, chilled-water pumps, terminal-side control, and whole-building savings

Calculation notes

Reporting units follow ASHRAE I-P convention: temperature in °F, pump head in ft, water flow in gpm, motor power in hp, cooling capacity in tons, and chilled-water plant efficiency in kW/ton.

From Sep 1 onward, condenser-water pump frequency and cooling-tower fan frequency were fully controlled by AI within the approved BAS operating bands.