Hybrid Air-Cooled and Water-Cooled Chiller Strategy for Energy and Water Optimization in a Hot, Water-Stressed Climate

Abstract

This case study presents the technical and economic evaluation of upgrading an existing water-cooled chiller plant to a hybrid configuration integrating inverter-driven air-cooled chillers with a retained water-cooled unit. The project is located in Hyderabad, India, where high ambient temperatures and increasing water scarcity create operational and financial challenges for conventional cooling tower–dependent HVAC systems. The study compares existing and proposed systems in terms of energy consumption, water usage, installation cost, maintenance expenditure, and five-year lifecycle cost. Results indicate substantial reductions in water consumption, operating cost, and maintenance complexity, with an estimated return on investment (ROI) of approximately 260% and a simple payback period of about two years. The findings demonstrate that hybrid chiller plants offer a practical balance between energy efficiency and water conservation in hot climates.

1. Background and Problem Statement

Commercial facilities in Hyderabad experience prolonged hot seasons with summer ambient temperatures reaching up to 45°C. Water-cooled chiller systems traditionally provide stable performance under such conditions but rely heavily on cooling towers, chemical water treatment, and continuous makeup water. Rising water tariffs, supply uncertainty, and maintenance demands prompted evaluation of a hybrid solution that reduces dependence on cooling towers while preserving reliable cooling capacity.

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2. Existing HVAC System Overview

The existing plant operates on a primary–secondary pumping configuration and includes:

- Three 100 TR water-cooled chillers (to be replaced)
- Three 125 TR cooling towers (to be removed)
- One 217 TR water-cooled chiller (retained)
- One 236 TR cooling tower (retained)
- Connected cooling load: approximately 200 TR

The system faces increasing maintenance, scaling and water treatment requirements, and operational risk due to inconsistent water supply.

Figure 1. Existing chiller plant configuration with multiple water-cooled chillers and cooling towers.

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3. Objectives of the Upgrade

- Reduce cooling tower water consumption
- Lower operational and maintenance costs
- Introduce energy-efficient inverter-based chiller technology
- Improve system reliability and ease of maintenance
- Optimize lifecycle cost while maintaining cooling performance

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4. Hyderabad Climate and Operational Constraints

Key site conditions influencing system design include:

- Peak ambient temperatures up to 45°C
- High wet-bulb conditions affecting cooling tower performance
- Increasing water tariffs and restrictions
- Risk of downtime from municipal water supply interruptions
- These constraints increase the economic and reliability risks associated with fully water-cooled plants.

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5. Proposed Hybrid Chiller Configuration

The retrofit replaces three 100 TR water-cooled chillers with 300 TR inverter air-cooled screw chillers, while retaining one 217 TR water-cooled unit and its cooling tower.

Key features:

- Common chilled-water header
- Automated load sharing and sequencing
- Daytime preference for water-cooled operation during peak load
- Nighttime and part-load operation using air-cooled chillers

Figure 2. Proposed hybrid chiller plant layout showing integration of air-cooled and retained water-cooled equipment.

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6. Operational Strategy and Estimated Performance

Period	Chiller Type	Ambient Range	Estimated Efficiency
Daytime	Water-Cooled	35–45°C	0.6–0.7 kW/TR
Nighttime	Air-Cooled	24–35°C	0.4–0.5 kW/TR

Air-cooled chillers benefit from lower nighttime ambient temperatures and inverter-driven compressor operation. The retained water-cooled unit provides stable performance under peak daytime conditions.

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7. Methodology

Performance and economic evaluation are based on calculated analysis using typical operating assumptions:

Average cooling load: 115 TR (90 TR for 9 months, 190 TR for 3 months)

Annual operating hours: 8,760 hours

Electricity tariff: ₹8.8 per kWh

Water tariff: ₹170 per kL

Existing system efficiency: 0.76 kW/TR

Hybrid system efficiency: 0.50 kW/TR

Energy consumption is determined from load, kW/TR, and annual hours. Lifecycle cost includes installation, maintenance, energy, and water cost over five years.

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8. Installation Cost Comparison (DSR 2025 Basis)

Equipment	Water-Cooled (300 TR)	Air-Cooled (300 TR)
Chiller Cost	₹8,141,100	₹7,579,800
Cooling Tower	₹931,092	—
Total	₹9,072,192	₹7,579,800

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9. CAMC Cost Comparison (5 Years)

Component	Water-Cooled	Air-Cooled
Annual CAMC per TR	₹2000	₹1300
Cooling Tower CAMC	₹5.0 Lakhs	—
5-Year Total	₹35.0 Lakhs	₹19.5 Lakhs

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10. Water Consumption Impact

Cooling tower makeup water: 30 kL/day

Annual water consumption: 10,950 kL

Five-year water cost: ₹9,307,500

Air-cooled system: No cooling tower makeup water

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11. Lifecycle Cost Summary (5 Years)

Cost Type	Water-Cooled (₹)	Hybrid (₹)
Installation	9,072,192	7,579,800
CAMC	3,500,000	1,950,000
Water Charges	9,307,500	0
Energy Cost	29,486,160	22,162,800
Total	51,365,852	31,692,600

Figure 3. Lifecycle cost comparison between water-cooled and hybrid systems.

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12. Financial Performance

Total 5-year savings: ₹19,673,252

Annual savings: ₹3,934,650

ROI: ~260%

Payback period: ≈ 2 years

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13. Advantages Observed

Elimination of major cooling tower infrastructure

No water treatment for replaced capacity

Reduced maintenance workload

Improved part-load efficiency

Lower installation and lifecycle costs

14. Assumptions and Limitations

Results are based on calculated estimates aligned with industry efficiency ranges

Actual performance may vary due to ambient fluctuations and control strategies

Pumping energy is assumed comparable in both systems

Post-installation measurement is recommended for validation

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15. Lessons Learned

Hybrid plants combine strengths of both chiller technologies

Water cost can outweigh marginal efficiency differences

Sequencing controls are critical to savings

Nighttime air-cooled operation significantly reduces water dependence

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16. Conclusion

The hybrid chiller strategy evaluated for this Hyderabad facility provides a technically sound and economically attractive solution to reduce water usage, maintenance burden, and lifecycle cost while maintaining reliable cooling performance. The approach offers a scalable model for facilities located in hot, water-constrained regions.

References

ASHRAE Handbook—HVAC Systems and Equipment

ASHRAE Handbook—Fundamentals

ASHRAE Standard 90.1

AHRI Standard 550/590

CPWD DSR 2025

BEE ECBC Guidelines

Manufacturer chiller performance catalogs