

Utilizing Fuel Cell Heat and Absorption Chillers to Reduce Cooling Power in Data Centers

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Data center cooling represents a growing share of total facility power consumption, particularly as AI-driven workloads increase rack densities and thermal loads. At the same time, on-site power generation technologies such as phosphoric acid fuel cells (PAFCs), produce substantial quantities of high-grade heat that can be utilized, counterintuitively, as a reliable source of cooling.

This white paper evaluates the technical feasibility of integrating single-effect lithium bromide (LiBr) absorption chillers with HyAxiom M400 PAFC heat to reduce grid-supplied electrical power for combined cooling heat and power (CCHP). When properly engineered, absorption chillers can reduce cooling-related electrical power consumption by approximately 40–90%, depending on heat-rejection strategy and climate conditions. Lower reductions (~40%) are achievable using dry coolers, while higher reductions (up to ~90%) are achievable using cooling towers under favorable wet-bulb conditions.

These reductions assume continuous operation and represent theoretical upper bounds; real-world performance depends on climatic conditions and operating temperature setpoints. Nevertheless, even partial displacement of electric chillers can materially improve Power Usage Effectiveness (PUE), reduce electrical infrastructure requirements, and lower operational carbon intensity.

This paper demonstrates that absorption chillers are not merely a theoretical concept for data centers but a commercially mature, scalable technology. Payback periods of 2-4 years are achievable when applied within appropriate temperature envelopes and integrated into hybrid cooling architectures.

What Is an Absorption Chiller?

An absorption chiller (also known as a vapor-absorption chiller or VAC) is a thermally driven refrigeration system that uses heat rather than electricity as its primary energy input. In a typical single-effect LiBr absorption chiller:

- Water is the refrigerant
- Lithium bromide is the absorbent
- Cooling is produced by evaporating water under vacuum
- Heat input drives separation of the refrigerant from the absorbent

Near-vacuum conditions are used because water evaporates at significantly reduced temperatures. At a typical operating pressure of 0.12 PSI, water evaporates at only 40°F. Unlike vapor-compression chillers (also known as electric chillers), vapor-absorption chillers contain no large compressors, resulting in low electrical consumption and quiet operation. In essence, electric chillers use high-grade electricity to move low-grade heat while absorption uses low-value thermal energy.

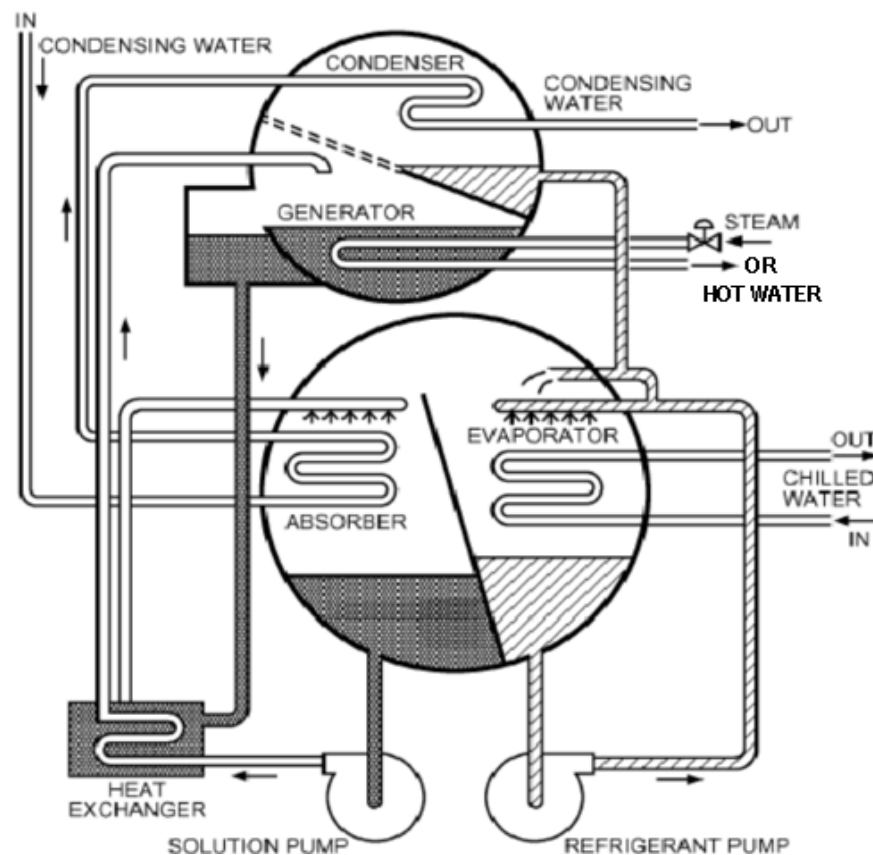


How Absorption Chillers Function

The core thermodynamic cycle consists of four main components:

1. **Evaporator** – Produces chilled water by evaporating refrigerant (water) under vacuum
2. **Absorber** – Absorbs refrigerant vapor into the LiBr solution
3. **Generator** – Uses heat (e.g., hot water at ~140–250°F for a single effect chiller) to separate refrigerant
4. **Condenser** – Rejects heat to ambient via cooling water or air, external source of cooling is required (dry cooler or cooling tower)

Electrical input is limited to solution pumps, purge systems, and controls. See the diagram below for more information.



Source: ASHRAE Handbooks. Refrigeration. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2006

Absorption chillers have demonstrated service lives of 25–40 years, often exceeding those of electric chillers. While early designs had operational challenges, modern machines benefit from:

- Automated air purge systems
- Improved materials and corrosion inhibitors
- Advanced controls and monitoring
- Factory-tested modular construction

Benefits of Absorption Chillers

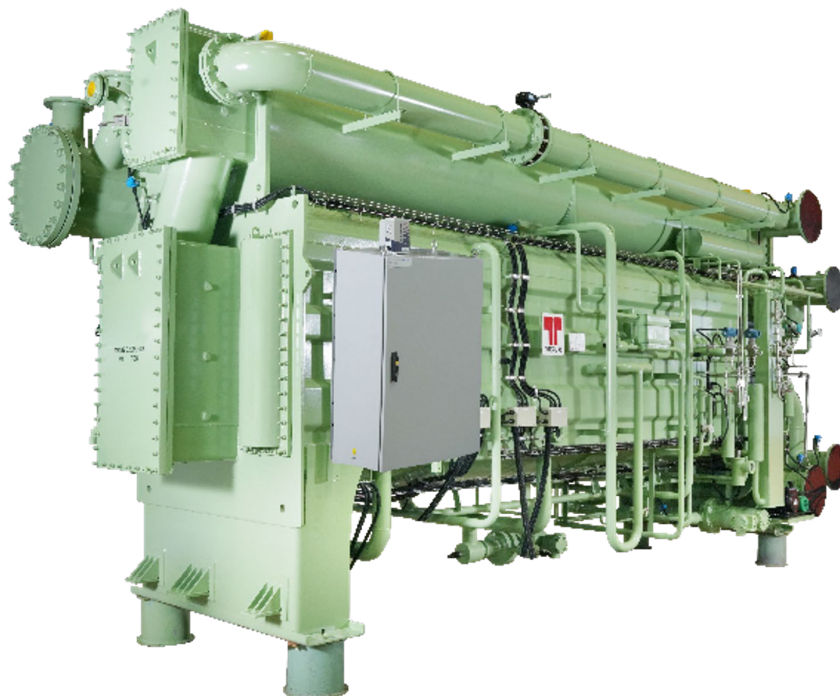
Key advantages include:

- Very low electrical power consumption (~0.02 kW/ton)
- Ability to utilize heat from CHP
- Reduced peak electrical demand
- Long service life
- Compatibility with high chilled-water temperatures
- No substances with global warming potential
- Reduced operational carbon intensity compared to electric chillers
- Potential increased CCHP efficiency in excess of 65%

Why Aren't Absorption Chillers Used More Often?

Despite their maturity, adoption has been limited by:

- Higher upfront capital cost
- Maintenance requirements
- Larger footprint
- Integration complexity
- Dependence on cooling water systems
- Perceived reliability risk (often outdated)
- Resistance to change



Reducing Power Usage in Data Centers

Cooling Energy in Data Centers

Data center energy demands are on track to comprise over 9% of the total US electricity demands by 2030.¹ Cooling systems typically account for 20-40% of total data center energy consumption, with facilities relying on air-cooled or water-cooled electric chillers falling on the higher end of this range.

Data centers are not the only sector driving up electricity demand. Increases in manufacturing due to on-shoring, and the electrification of transportation and shift from fossil fuels to electric heat pumps all contribute to increased power scarcity and higher rates. As a result, U.S. electricity demand is expected to grow by 25% and rates could increase by 15% to 40% by 2030.² These factors coupled with the growth of AI has resulted in the search for less energy intensive methods of data center cooling.

Conventional Cooling Technologies

Air-cooled electric chillers:

- Peak electrical consumption: ~1.15 kW/ton
- High peak power draw
- Performance degrades at high ambient temperatures

Water-cooled electric chillers:

- Peak electrical consumption: ~0.8 kW/ton
- Higher efficiency but usually require cooling towers
- Dry cooling is possible but results in similar efficiency to air-cooled chillers
- Increased water consumption and operational complexity
- High upfront capital cost

Challenges with Heat Recovery from Other Generation Sources

Many on-site generation technologies produce waste heat, but recovery is often limited:

- Diesel / natural gas generators – Intermittent, not suitable for base cooling
- Gas turbines – High exhaust temperature, but poor part-load operation
- Solid oxide fuel cells (SOFCs) – High temperature but slow reaction to load changes

HyAxiom M400 PAFC Heat from CHP

HyAxiom PAFC systems produce hot water up to ~250°F, with common operating points around 200°F, making them well-matched to single-effect absorption chillers. Below are some of the characteristics PAFCs offer:

- High availability ($\geq 97\%$)
- Fast ramp rates (+10 kW/s, +/-20 kW/s)
- Continuous base-load operation
- A steady source of heat for combined cooling heat and power (CCHP)
- Substantially lower emissions than reciprocating engines or turbines

Key Engineering Considerations

Choice of Cooling Technology

Absorption chillers use heat to produce chilled water but need external cooling, typically from cooling towers. Cooling towers operate in many climates, achieve low chiller temperatures, and are electrically efficient by using both latent and sensible heat transfer. However, they consume significant water through evaporation and blowdown. Alternatives include cooling with large bodies of water, which is situational, or using adiabatic or dry cooling. Dry cooling is closed-loop and only needs water for the initial fill but may not suit hot climates. Adiabatic cooling uses less water than towers and can operate dry in cold weather. This paper will focus on cooling towers and dry coolers.

Temperature Envelope

Traditional HVAC chilled water applications usually necessitated the use of cooling towers due to the low chilled water temperature setpoint requirement (~45°F). However, modern data centers typically operate in a temperature envelope of 68–99°F allowing the use of dry cooling. Absorption chillers can produce water as cold as ~34°F, but lower temperatures significantly reduce efficiency and are less relevant for modern data center facilities.

Water Quality

Proper water chemistry management is critical, particularly for cooling towers. Dry cooler systems substantially reduce operational risk related to scaling, corrosion, and biological growth since they operate in a closed loop without requiring evaporative cooling.

Reliability and Redundancy

Modern single-effect absorption chillers achieve 0.99–0.995 availability with routine maintenance, which is roughly the same as electric chillers. Typical designs assume N+1 redundancy, with N+2 reserved for extreme availability targets (5-9s).

When properly engineered and maintained, absorption chillers are reliable, predictable assets.

Geographic Considerations

The region where the absorption chiller will be installed is important primarily due to weather conditions and water availability. The local climate will dictate whether dry cooling or cooling towers can be used with the absorption chiller. Water-stressed areas may not be appropriate for new cooling tower installs.



Heat Rejection Strategies for Absorption Chillers

Dry Cooler Heat Rejection

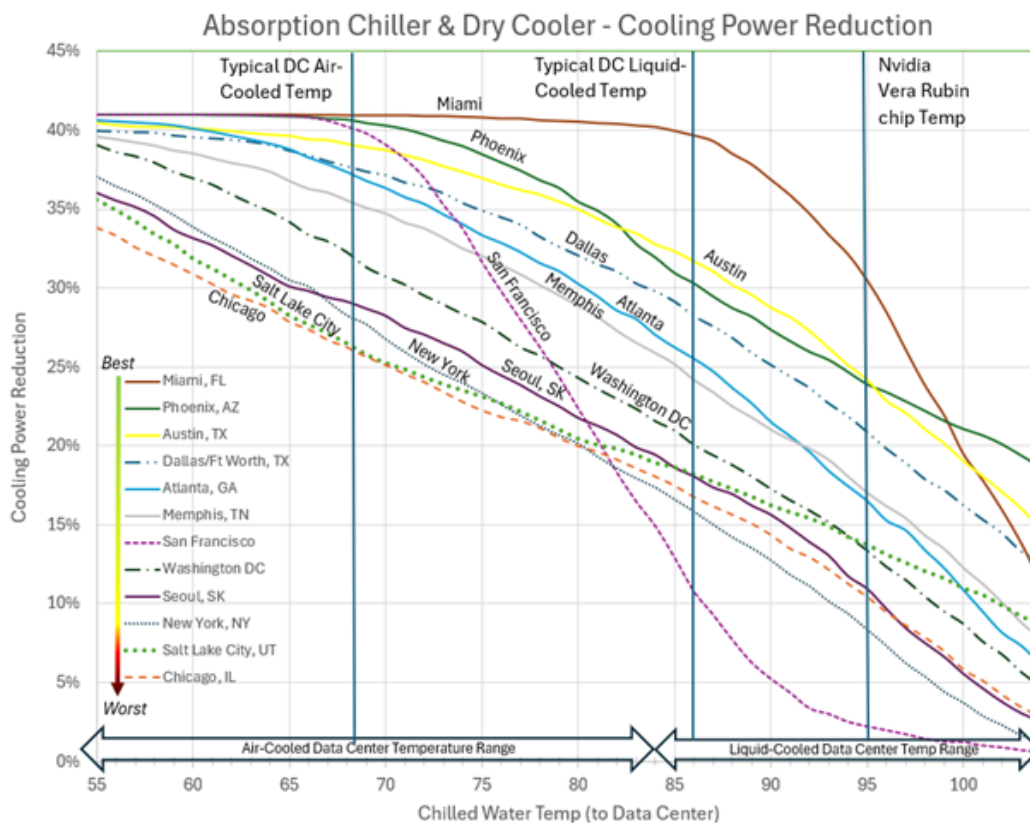
Dry coolers reject heat directly to ambient air and offer:

- No water consumption
- Simplified permitting
- High reliability
- Compatibility with water-constrained regions

Typical performance:

- Peak electrical consumption: ~0.19-0.28 kW/ton (depending on footprint)

Using dry coolers, absorption chillers can reduce cooling-related electrical power consumption by ~40% relative to air-cooled electric chillers. However, energy savings are dependent on the data center architecture and geographic location. As can be seen in the figure below, areas with hot climates can save large amounts of power while cooler locations may be better off relying on dry cooling alone with adiabatic assist for hot summer days. This is especially true for data centers using liquid cooling or the latest generation chips such as Nvidia's Vera Rubin for AI applications. Note that this figure is valid when absorption chillers are used with HyAxiom fuel cells.



Energy savings are also highly dependent on the dry cooler selection. Energy savings approaching 50% can be realized at the expense of greatly increased dry cooler footprint. Note that this increase in footprint does not necessarily mean an increase in capital cost.

Cooling Tower Heat Rejection

Cooling towers provide superior thermodynamic performance but introduce:

- Water consumption and chemical treatment
- Increased operational complexity
- Regulatory and siting constraints

Typical performance:

- Peak electrical consumption: ~0.1 kW/ton
- Water consumption: ~12 gallons/min for every MW of compute (varies with wet-bulb temperature, load factor and cycles of concentration)

The electrical consumption of a cooling tower is ~10% that of an electric chiller which allows for cooling power reductions approaching 90% with proper cooling system design. However this comes at the expense of evaporating large quantities of water, a cooling strategy which would be misapplied in water-constrained regions.

Use Cases for Cooling Towers and Dry Coolers

In general, the best use case for cooling towers is when the highest electrical efficiency is demanded, water is available, and the consumption of water is not heavily scrutinized. When consuming large quantities of water is not an option then dry cooling is the best-suited solution. However, the use cases can vary on a multitude of different factors include but are not limited to what is listed below.

Category	Cooling Tower (Evaporative)	Dry Cooler (Air-Cooled)
Suitability for Absorption Chillers	Well-suited	Suitable, but situational
Typical Cooling Water Temp	~75–90°F (24–32°C)	~90–115°F (32–46°C)
Impact on Chiller COP	Higher COP	Lower COP
Fan Power	Lower	Higher
Heat Exchanger Size	Smaller	Much larger
Water Use	High	None
Water Treatment Required	Yes	No
Maintenance Complexity	Higher (scaling, biofouling)	Lower
Legionella Risk	Present	None
Freeze Protection	Required	Glycol needed
Capital Cost	Lower (typically)	Higher (large coils)
Operating Cost	Lower	Higher
Footprint	Moderate	Larger

Applications Where Absorption Chillers Are Not Recommended

Some applications where absorption chillers would be misapplied are:

- Cool climates where dry cooling alone meets setpoint >90% of the year
- Data centers requiring sustained <55°F chilled water without using a cooling tower
- Sites without a continuous, steady heat source
- Locations where regular on-site maintenance is not feasible

Integrating HyAxiom M400 Fuel Cells and Absorption Chillers in Data Centers



Hybrid Cooling Strategy Overview

Absorption chillers are best deployed as part of a hybrid cooling architecture, operating alongside electric chillers or dry coolers. They are not intended to fully replace conventional systems but to displace electrical cooling energy when waste heat is available. A key advantage of this design is that it allows dry cooling at temperatures above the chilled water set point (e.g. using ambient air at 80°F to provide chilled water at 68°F), a feat which is otherwise impossible without employing an energy-intensive refrigeration loop. However, once the ambient air temperature falls below ~15°F of the required chilled water setpoint, the datacenter will save energy by switching to dry cooling only mode without operating any chillers.

Presented here are one of many potential cooling strategies that could be employed. The ideal cooling strategy should serve the specific needs of the data center.

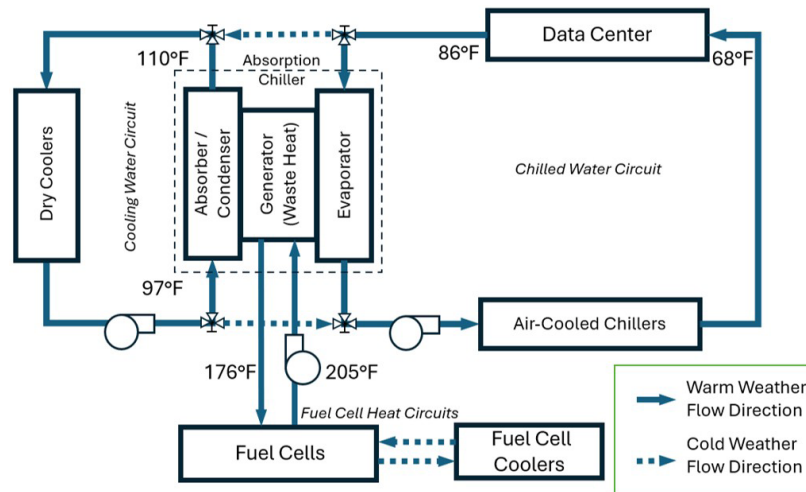
Air-Cooled Data Center Architecture

In predominantly air-cooled data centers:

- Absorption chillers provide chilled water to thermal energy storage (TES), computer room air handlers (CRAH) or secondary heat exchangers
- Electric chillers remain as backup, for peak loads and trim cooling
 - Backup Cooling (for mission critical facilities):
 - When the absorption chiller is offline, such as for annual maintenance.
 - If waste heat loads are reduced or unavailable thereby limiting chilled water output below what the datacenter requires
 - Peak Loads:
 - Applies to extreme weather events, temporary IT overprovisioning and certain transient operational conditions
 - Electric chillers ramp faster than absorption chillers and can respond more quickly to sudden increases in cooling demand. However, note that thermal energy storage could also address this
 - Trim Cooling:
 - Absorption chillers handle base thermal load. Electric chillers “trim” periods where ambient temperature exceeds absorption limits
 - Electric chillers operate at reduced capacity during times when cooling demand slightly exceeds absorption chiller capacity
 - Trim operation minimizes electric chiller runtime and energy use
- High chilled-water temperatures (68–86°F) improve absorption performance

This architecture provides inherent redundancy and simplifies failure management. A simplified diagram of this approach can be seen below.

Air-Cooled Data Center Chilling Diagram



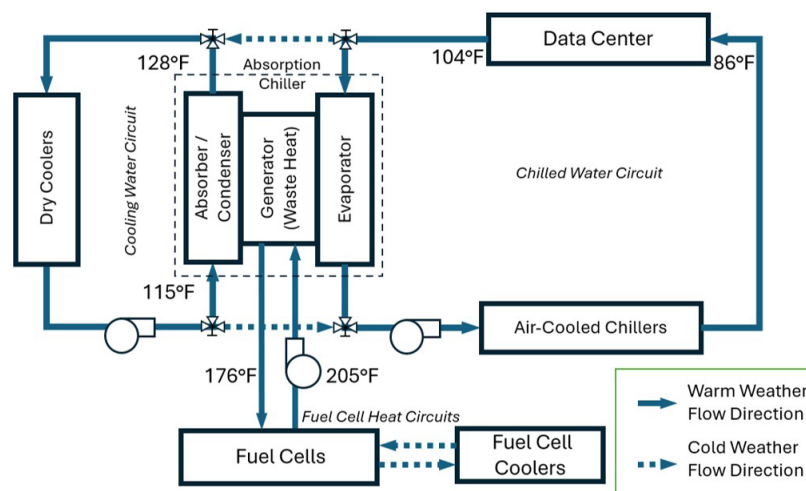
Liquid-Cooled Data Center Architecture

For liquid-cooled data centers:

- Absorption chillers supply facility water to thermal energy storage or coolant distribution unit (CDU) heat exchangers
- Higher supply temperatures align well with modern IT requirements
- Same as with the air-cooled strategy, electric chillers serve as backup, for peak loads and trim cooling

The primary differences between liquid and air-cooled systems are the cooling and chilled water temperature requirements. Latest generation chips use liquid cooling and allow for higher chilled water temperatures which allow for higher temperatures in the cooling water loop. This allows for dry cooling at higher ambient temperatures and/or more economical dry cooler selections. A simplified diagram of this approach can be seen below.

Liquid-Cooled Data Center Chilling Diagram



Economics and Business Case

Relative Cost Comparison

Representative all-in costs for an absorption chiller system with dry cooling are approximately 2-3x those of a baseline air-cooled electric chiller on a \$/ton basis. However, electrical infrastructure downsizing, energy savings and unlocking additional compute capacity can materially offset this difference.

Illustrative Example

Assumptions:

- 10 MW liquid-cooled data center with continuous year-round operation
- Electric chiller: 1.0 kW/ton
- Absorption chiller parasitic: 0.02 kW/ton
- \$0.10/kWh average electricity cost
- Dry cooler: 0.28 kW/ton (**Option A**)
- Cooling tower: 0.07 kW/ton (**Option B**)

Result:

- **Option A:** Dry-cooled absorption system achieves ~40% average cooling power reduction and CO₂ offset of ~4,600 tons/yr compared to average US powerplant emissions
- **Option B:** Tower-cooled absorption system achieves up to ~90% reduction and CO₂ offset of ~11,500 tons/yr

Minimum payback periods on the order of 2-4 years are achievable under favorable electricity pricing and duty cycles.

Below is a table showing the breakdown for a 5 MW block within a data center. This data can be extrapolated for larger data centers. Power consumption and costs can vary widely depending on install location, chiller & dry cooler supplier.

	Baseline	With Absorption Chillers			
	Electric Chillers Only	Absorption Chiller	Electric Chillers	Total	
Fuel Cell Efficiency, LHV	44%	71%			+27%
Cooling (Tons)	2,843	1,460	1,383	2,843	
Standard Chilling Electric Load (MW)	2.84	0.41	1.38	1.79	-1.05 MW
Annual Consumption (GWh)	24.9	3.6	12.1	15.7	-9.2 GWh
Capex (\$M, Approx)	\$3.0M	\$3.7M	\$1.5M	\$5.2M	+\$2.2 (1-time)
Electrical Cost / Yr. (\$M) ¹	\$2.5M	\$0.36M	\$1.21M	\$1.57M	-\$0.94M/year

Conclusion

Technology Maturity and Deployment Readiness

Absorption chillers are a mature technology with decades of deployment across industrial, institutional, and CHP applications. Recent advancements in controls, materials, and monitoring have significantly improved reliability and ease of integration.

The primary barrier to adoption in data centers is not technical feasibility but design familiarity and integration mindset.

Recommendations

Absorption chillers integrated with CHP-capable M400 PAFCs offer a credible pathway to:

- Reduce cooling-related electrical power
- Improve PUE and sustainability metrics
- Leverage otherwise wasted thermal energy
- Increase resilience through hybrid architectures

They are best suited for:

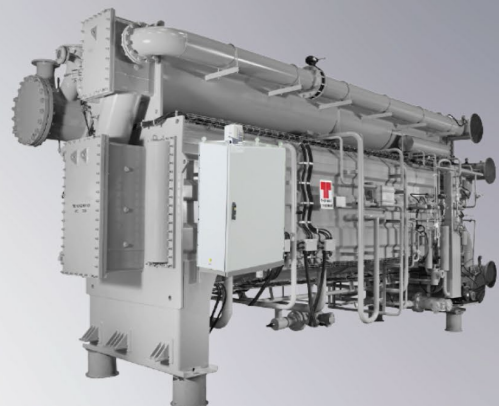
- Facilities with on-site fuel cells or other continuous heat source
- High chilled-water temperature designs
- Regions with high electricity costs
- Water-constrained environments favoring dry cooling

As data center thermal requirements continue to evolve, thermally driven cooling technologies represent an increasingly valuable tool in the engineer's design toolkit.

HyAxiom PureCell® Model 400



Absorption Chillers



Sources

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2. <https://www.icf.com/insights/energy/impact-rapid-demand-growth-us#:~:text=In%20a%20sudden%20shift%20from,some%20rates%20might%20even%20double.>



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