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TECHNOLOGIES

REFERENCE DESIGN #502

HIGH-EFFICIENCY COOLING FOR THE 1 GW AI FACTORY

High Condenser Temperature System
Design featuring CenTraVac[®] Simplex

A scalable reference design that optimizes
cooling to unlock additional power and space.





INTRODUCTION

Artificial intelligence is driving massive growth in data center demand — and advanced cooling is critical to keep innovation running. Trane leads the way with proven thermal management solutions for AI factories and data centers of all sizes.

This reference design provides:

- ✓ A 1 GW cooling blueprint for AI factory applications
- ✓ Integrated air- and liquid-cooling configurations for NVIDIA racks
- ✓ Guidance on CDUs, fan coil walls, chillers, dry coolers, pumps and facility piping
- ✓ A foundation for mechanical design that complements electrical and controls systems





DESIGN OVERVIEW

Temperature and Flow Rates

This table summarizes temperature and flow rate requirements for the water-cooled chillers in this reference design. These values represent an AI factory installed in Albuquerque, NM and can be adjusted for specific applications.

Technical Loop Supply Temperature: 30°C (86°F)

Technical Loop Return Temperature: 40°C (104°F)

Fan Coil Wall Supply Air Temperature: 27°C (80.6°F)

Optimized condenser temperatures
[Learn more](#)

| | Medium Temperature (Airside) | High Temperature (Liquid Direct to Chip) |
|--|------------------------------|--|
| Total Block Load | 13.74MW (3,906T) | 102.4MW (29,120T) |
| Load Requirement/Chiller | 6.87MW (1,953T) | 10.24MW (2,912T) |
| Evaporator Flow Rate/Chiller | 9,809 LPM (2592.9 GPM) | 13,187 LPM (3,485.1GPM) |
| Facility Loop Temperature (Return) | 32°C (89.6°F) | 36°C (96.8°F) |
| Facility Loop Temperature (Supply) | 22°C (71.6°F) | 26°C (78.8°F) |
| Facility Loop Fluid | Water | Water |
| Condenser Flow Rate/Chiller | 11,854 LPM (3130.5 GPM) | 15,526 LPM (4,103.3 GPM) |
| Heat Rejection Loop Temperature (High) | 58.9°C (138°F) | 58.9°C (138°F) |
| Heat Rejection Loop Temperature (Low) | 48.9°C (120°F) | 48.9°C (120°F) |
| Heat Rejection Loop Fluid | Water* | Water* |
| Max Ambient (Albuquerque, NM) | 40°C (104°F) | |
| Elevation (Albuquerque, NM) | 1,619m (5,312') | |

*Our recommendation is to utilize [freeze protection](#).

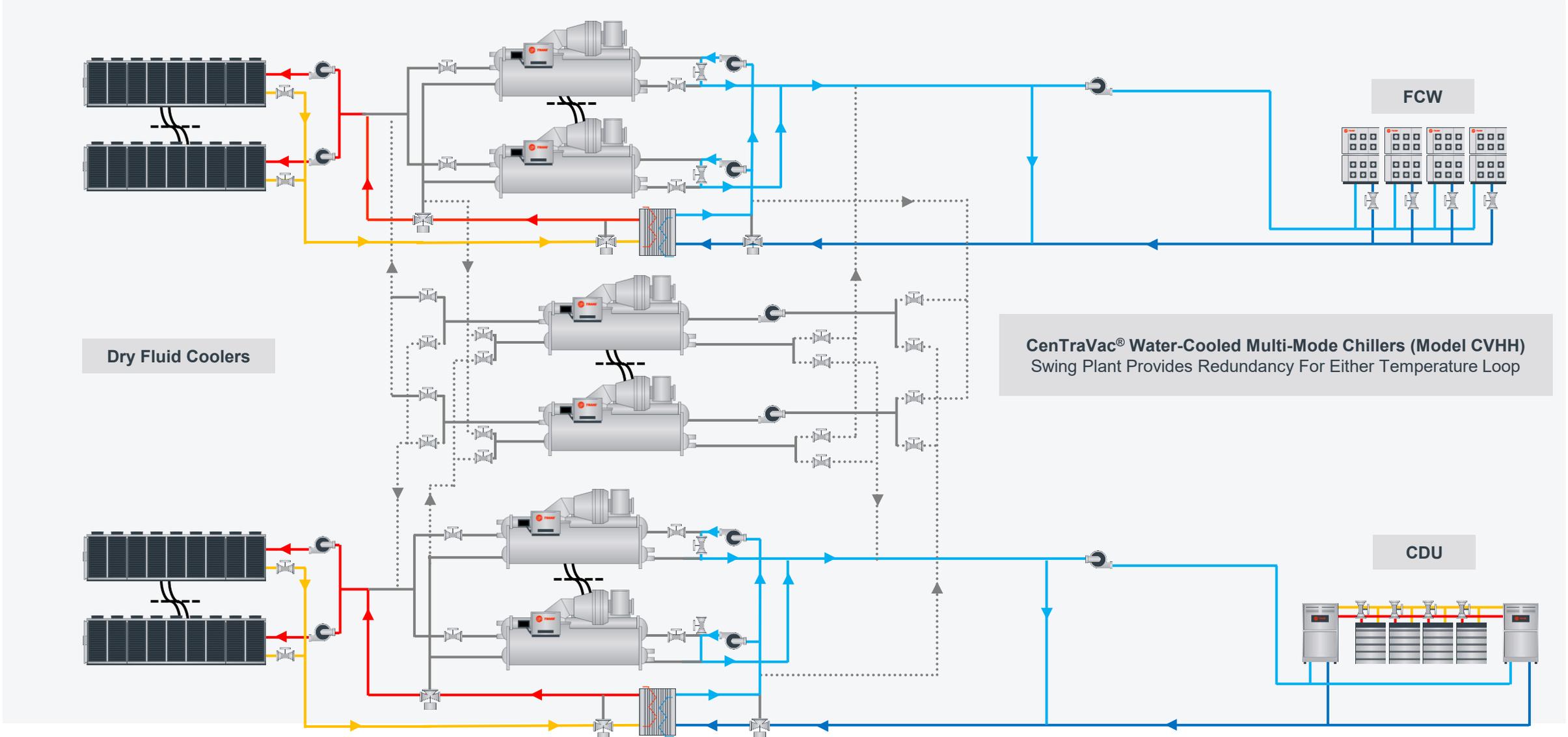
DESIGN OVERVIEW

Reference Diagram

✓ 1 GW mechanical cooling blueprint for AI factories

✓ Integrates air- and liquid-cooling systems

✓ Modular structure for scalability and serviceability



→ DESIGN OVERVIEW

Customer Outcomes



Reduce power use

- Optimizing for higher condenser water temperatures and greater delta T reduces overall plant energy use.
- Lower cooling power frees electrical capacity for compute, increasing token production and site profitability.
- Advanced controls balance chiller lift and pump energy to maintain top-tier PUE.



Future-ready design

- Designed to scale as chip densities and cooling needs evolve.
- Supports flexible mixes of liquid and air cooling.
- Dual-mode chillers enable smooth loop rebalancing without adding equipment.



Balanced total cost of ownership (TCO), redundancy and resiliency

- Swing chillers can serve high- or low-temperature loops, reducing the total chillers needed.
- Higher condenser water temperatures and greater delta T reduce dry-cooler count and overall plant power.
- High-efficiency water-cooled design with dry coolers cuts energy and water costs, improving ROI and sustainability.

→ SYSTEM BENEFITS

Water-cooled systems offer significant performance and sustainability advantages over air-cooled alternatives, delivering higher efficiency, low water use and helps to reduce environmental impact for large-scale AI data centers.

- Fewer chillers required due to larger capacity per unit
- Improved efficiency at higher condenser temperatures — better Power Usage Effectiveness (PUE)
- Dry coolers eliminate water use — Water Usage Effectiveness (WUE) = 0
- R-1233zd refrigerant (GWP 1) reduces carbon impact
- Dedicated temperature loops maximize free-cooling hours and improve the chiller efficiency of the high-temperature loop.



→ OPTIMIZATION APPROACH

Elevating Condenser Loop Temperature and Increasing Condenser Loop delta T

Impact to Chiller Plant

Raising a chiller's condenser temperature by 5.6°C (10°F) increases compressor lift, requiring more compressor energy. However, the higher lift enables large reductions in condenser water flow, cutting pump and dry cooler fan power. Overall system energy use drops because the added compressor work is offset by greater savings in these less efficient components.

Impact to Dry Cooler/Pumps

Raising the condensing leaving water temperature increases the temperature difference between the condenser fluid and ambient air, allowing each dry cooler to deliver more capacity. This can reduce the number of dry coolers needed or improve the efficiency of the existing units. Increasing condenser water delta T by 2.2°C (4°F) also lowers flow rates and pumping power, but the reduced flow may limit capacity and require additional dry coolers.

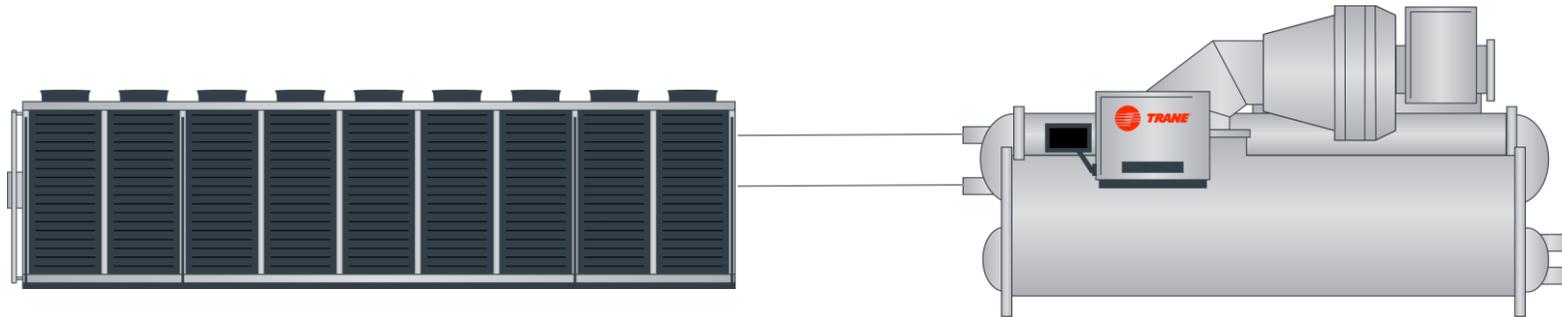
| Peak Power Impact | |
|-----------------------------------|-------------|
| Chiller Power | 7% ↑ |
| Dry Cooler Fan Power | 30% ↓ |
| Condenser Pump Power | 51% ↓ |
| Cooling Plant System Power | 9% ↓ |

| Optimization 1 (Reduced Dry Cooler Quantity): | |
|---|-----------|
| Free Cooling Operating Envelope | Reduced |
| Dry Cooler Footprint | 30% |
| Optimization 2 (Same Dry Cooler Quantity): | |
| Free Cooling Operating Envelope | Unchanged |
| Dry Cooler Footprint | Unchanged |

→ OPTIMIZATION APPROACH

Maximizes Token per Watt

Results of optimized chiller condenser temperatures on 1 GW AI Factory chiller plant efficiency



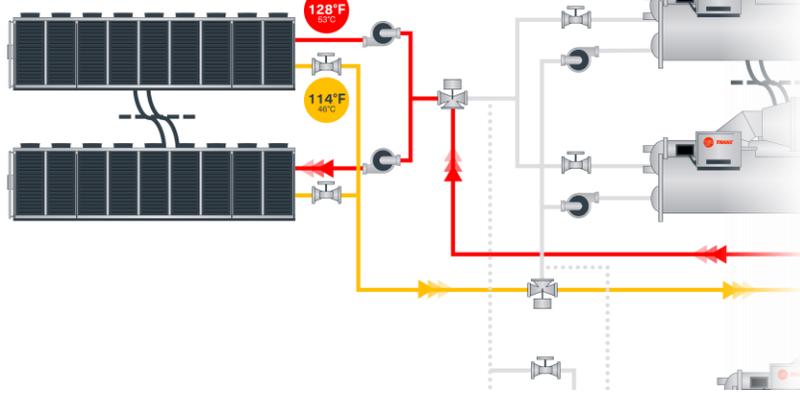
9% Cooling system improvement

22 MW Available to reallocate to IT



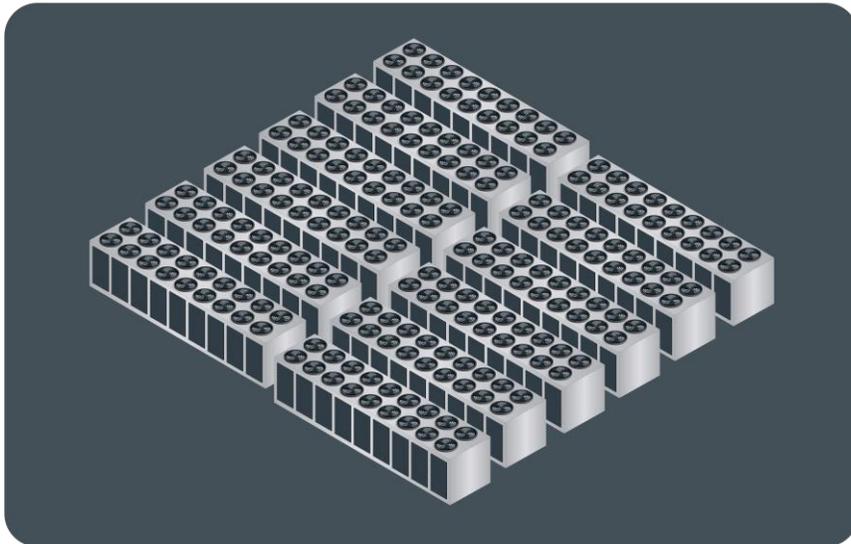
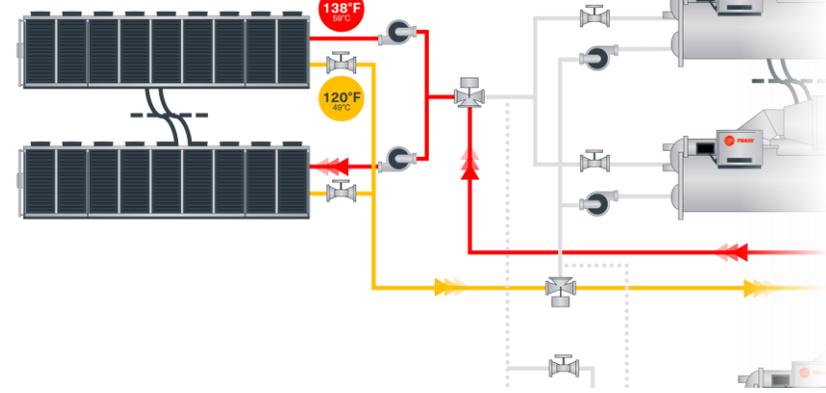
Design ambient outside air temp (104°)

Before optimization



Design ambient outside air temp (104°)

After optimization



Dry cooler field is reduced by 1/3

- ↑ 7% Chiller Power
- ↓ 30% Dry Cooler Fan Power
- ↓ 51% Condenser Pump Power
- ↓ 9% Cooling Plant System Power

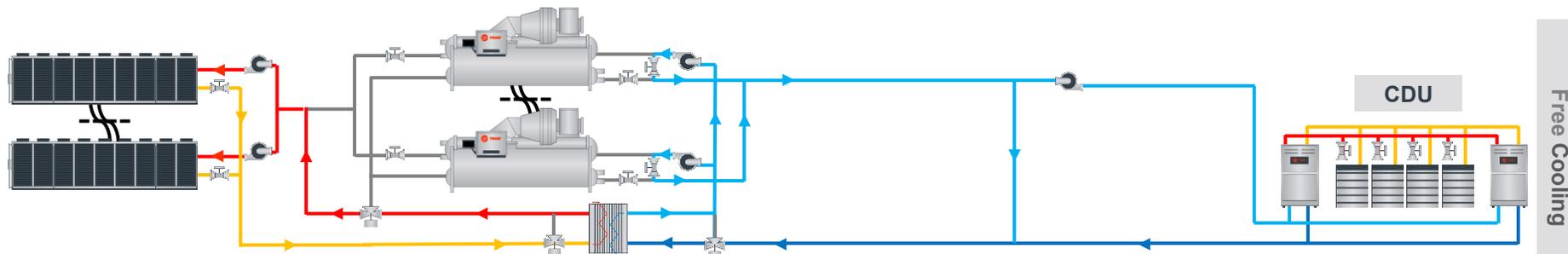
→ SYSTEM BENEFITS

Free Cooling

Cooling systems are designed for peak demand, but actual loads and outdoor temperatures vary. When conditions are favorable, this allows “free cooling.” This reference design uses dry coolers and a plate-and-frame heat exchanger to take advantage of those conditions.

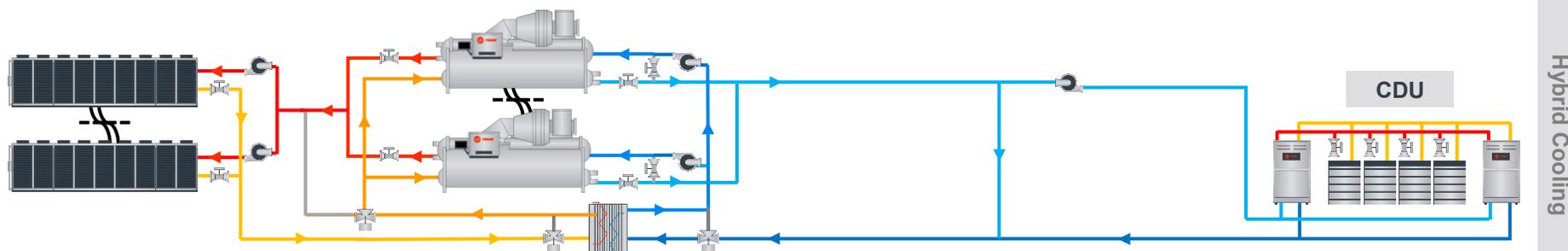
Mode 1: Free Cooling

Outdoor temperature is low enough to provide full cooling without mechanical assistance.



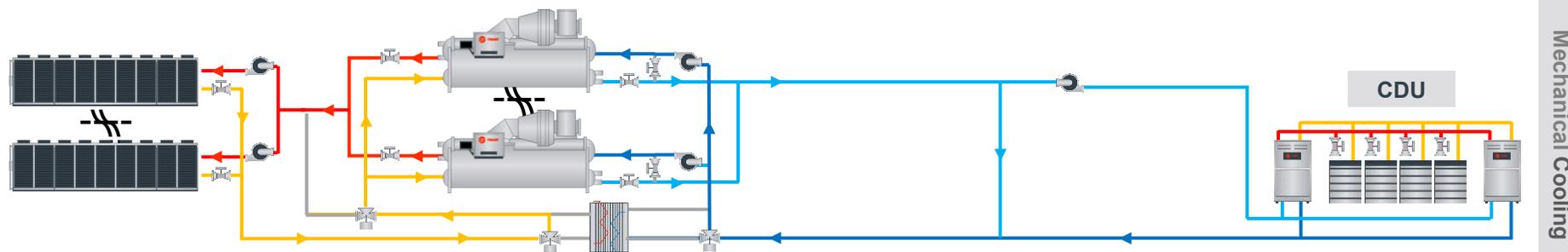
Mode 2: Hybrid Cooling

Outdoor temperature is lower than return temperature; exceeds temperature to provide full cooling capacity

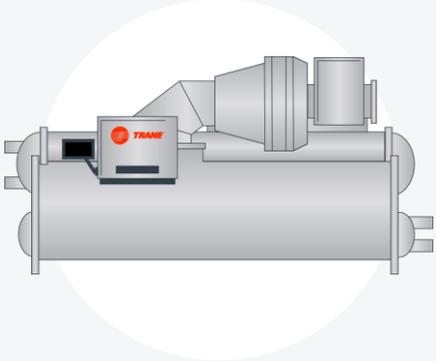


Mode 3: Mechanical Cooling

Outdoor temperature exceeds fluid return temperature — free cooling is bypassed.

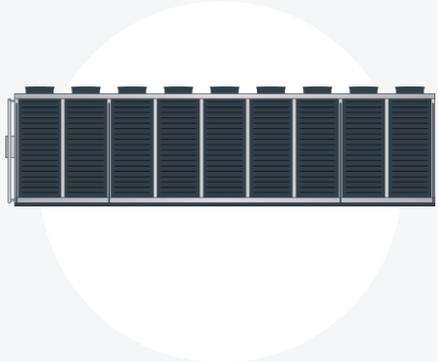


→ KEY SYSTEM COMPONENTS



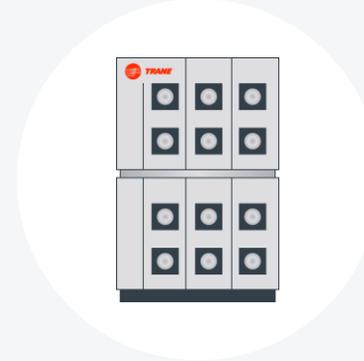
Water-Cooled Chillers

Trane CenTraVac® chillers are engineered for data centers, operating efficiently at higher water temperatures to deliver reliable cooling and improved overall plant performance.



Dry Coolers

Dry coolers reject heat directly to ambient air using dry-bulb temperature, eliminating water use and achieving a WUE of zero. Trane works with leading manufacturers to assure each system is optimized for site conditions and climate.



Fan Coil Walls

Trane Fan Coil Walls provide higher capacity, efficient air cooling in the data hall, using medium chilled-water temperatures to deliver added capacity where air cooling is needed most.



Coolant Distribution Units (CDUs)

Trane CDUs support the liquid-cooled portion of the data hall, separating facility and technical loops with a liquid-to-liquid heat exchanger for efficient, high-temperature cooling compatible with AI servers.

→ KEY SYSTEM COMPONENTS

CenTraVac® Water-Cooled Chillers Model CVHH

| Design Characteristic | Requirements |
|----------------------------------|--|
| Capacity Range | Up to 3,000 tons (11 MW) |
| Leaving Condenser Temp | Up to 68.3°C (155°F) |
| Facility Water Temperature Range | Up to 37.8°C (100°F) |
| Compressor | 2-stage Centrifugal Compressor |
| Heat Rejection Options | Dry Cooler/High Lift Application 6-pipe Heat Recovery Options |
| Refrigerant | Low GWP: R-1233zd |
| Restart After Power Loss | 43-76 Seconds Depending Upon Starter/Drive |
| Power Feed Requirement | 2300V to 12 kV Starter and Drive Options |



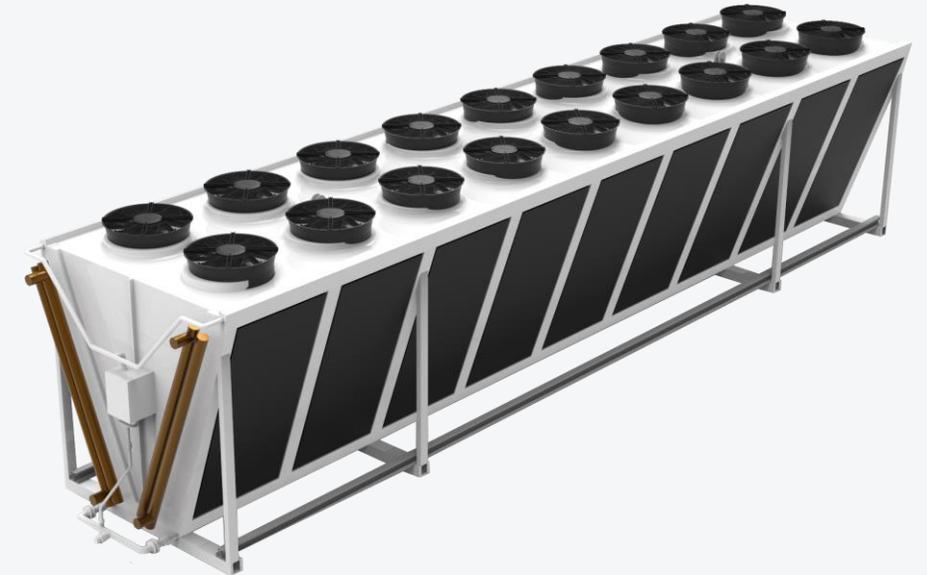
→ KEY SYSTEM COMPONENTS

Dry Cooler

| Design Characteristic | Requirements |
|------------------------|---------------------------------------|
| Capacity Range | 1,500 tons (5 MW+) |
| Max Ambient Dry Bulb | 62.8+°C (145+°F) |
| Fans | Variable Speed VFD or ECM Driven Fans |
| Power Feed Requirement | 380-480, 3 ph, 50/60 Hz |

Dry Cooler capacity and performance is dependent on local ambient extreme conditions.

* This is based on Albuquerque, New Mexico design conditions



There are many dry coolers solutions in the market. This design is based on a general dry cooler configuration. Specifications may change depending on the dry cooler used in application.

→ KEY SYSTEM COMPONENTS

Fan Coil Wall

| Design Characteristic | Requirements |
|----------------------------|--|
| Capacity Range | Up to 800 KW |
| Airflow Range | 110K CFM+ |
| Entering Air Temp | Up to 40°C (104°F) |
| Fan Type | ECM Direct Drive Fans |
| Additional Feature Options | Automatic Transfer Switch (ATS) Controller Capacitor Backup Condensate Pump Backdraft Dampers |
| Filtration | 2" or 4" Filters (MERV 8 or 11) |
| Harmonic Filtration | 5% or Less of Total Demand Distortion |
| Power Draw | < 6% of Capacity Being Cooled in KW |
| Power Feed Requirement | 415-480, 3-phase, 50/60 Hz |



→ KEY SYSTEM COMPONENTS

Coolant Distribution Unit (CDU)

| Design Characteristic | Requirements |
|--------------------------------------|---|
| Capacity Range | Up to 10 MW at 4°C (7.2°F) Approach |
| Effectiveness | >90% at 4°C (7.2°F) Approach |
| Minimum Pressure Head | 40 PSID + dp Across CDU |
| Design Secondary (PG 25) Supply Temp | Up to 45°C (113°F) |
| Design Facility Water Temperature | Up to 41°C (105.8°F) |
| Max Ambient Temperature Operation | 50°C (122°F) |
| Additional Feature Options | Scalable Solution Controls Teaming Application Pressure Independent Control Valve 316 Stainless Steel Plate Heat Exchanger Triple-Redundant Sensors in the Header |
| Secondary Side Filtration | 25-Micron Filtration |
| Power Draw | < 1% of Capacity Being Cooled in KW |
| Power Feed Requirement | 380-480, 3 ph, 50/60 Hz |



→ KEY SYSTEM COMPONENTS

Computer Room Air Handler (CRAH)

| Design Characteristic | Requirements |
|----------------------------|---|
| Capacity Range | 50kW to 360kW to support varied density zones |
| Airflow Range | 5,000 - 50,000k CFM |
| Fan Type | ECM Direct Drive Fans |
| Entering Air Temp | Up to 43°C (110°F) |
| Additional Feature Options | Automatic Transfer Switch (ATS) Controller Capacitor Backup Condensate Pump Motorized return air damper |
| Filtration | 2" (Merv 8 or 11) or 4" (Merv 8) Filters |
| Harmonic Filtration | 5% or Less of Total Demand Distortion |
| Deployment Configuration | Downflow horizontal discharge for electrical room cooling Flexible for downflow white space use Optional upflow configuration |
| Power Feed Requirement | 415-480, 3-phase, 60 Hz |

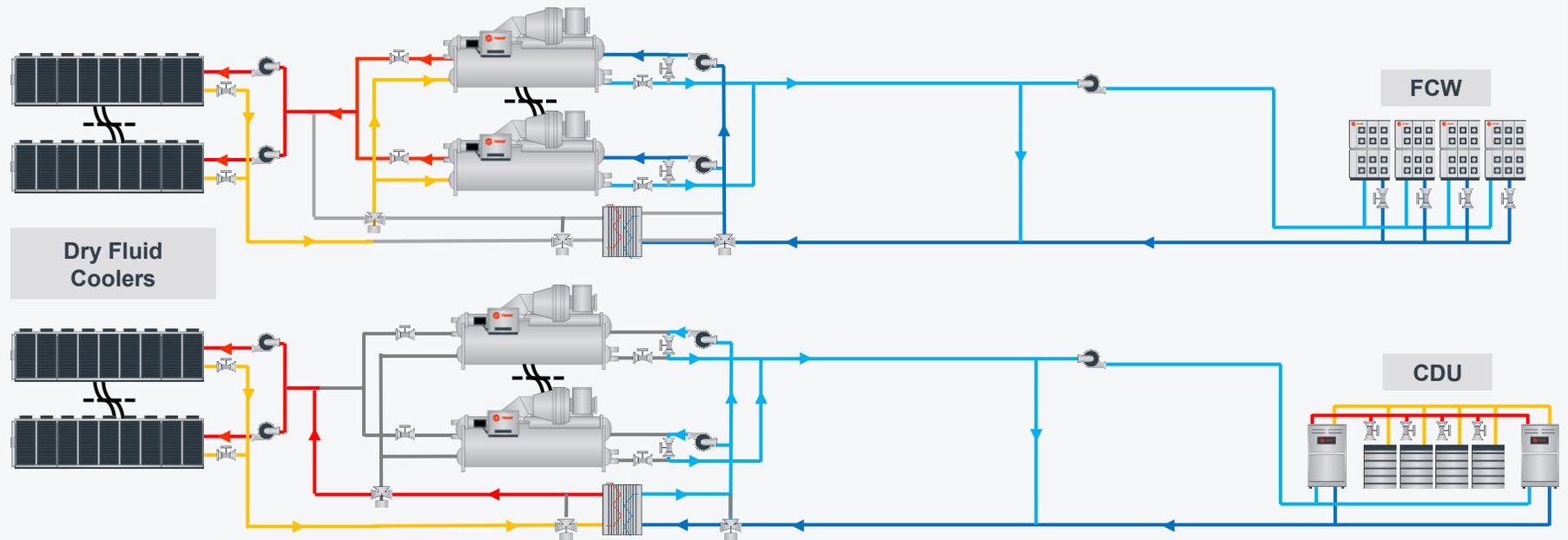


→ BEST PRACTICES

Efficiency

Dual-temperature chiller plant, dedicated low and high temperature chillers

- Best used when load ratios and temperature requirements are well defined and stable
- Separate loops eliminate unnecessary lift, allowing chillers to be selected and optimized specifically for each temperature band
- Higher-temperature loops enable more free-cooling hours, improving annualized efficiency
- Avoids the energy waste of single-temperature mixing strategies



Mechanical Cooling

Free Cooling

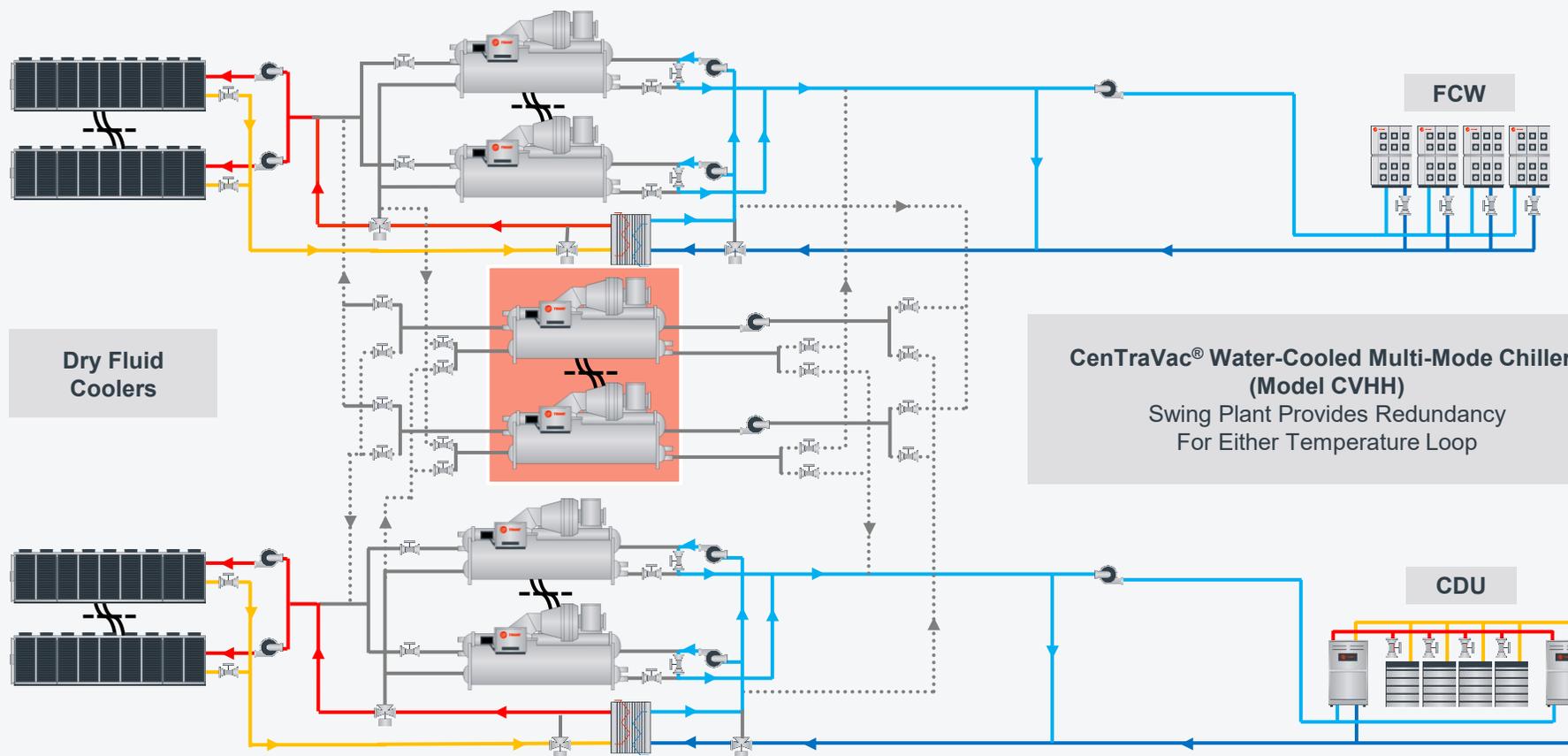
→ BEST PRACTICES

Redundancy

Dual-temperature plant with swing chillers

A dual-temperature chiller plant with swing chillers allows redundant units to be flexibly assigned to either the high- or low-temperature loop, reducing the total number of chillers needed when full dual-loop redundancy isn't required.

The swing chillers are selected for multiple modes of operation to ensure they can serve either loop.



Dry Fluid Coolers

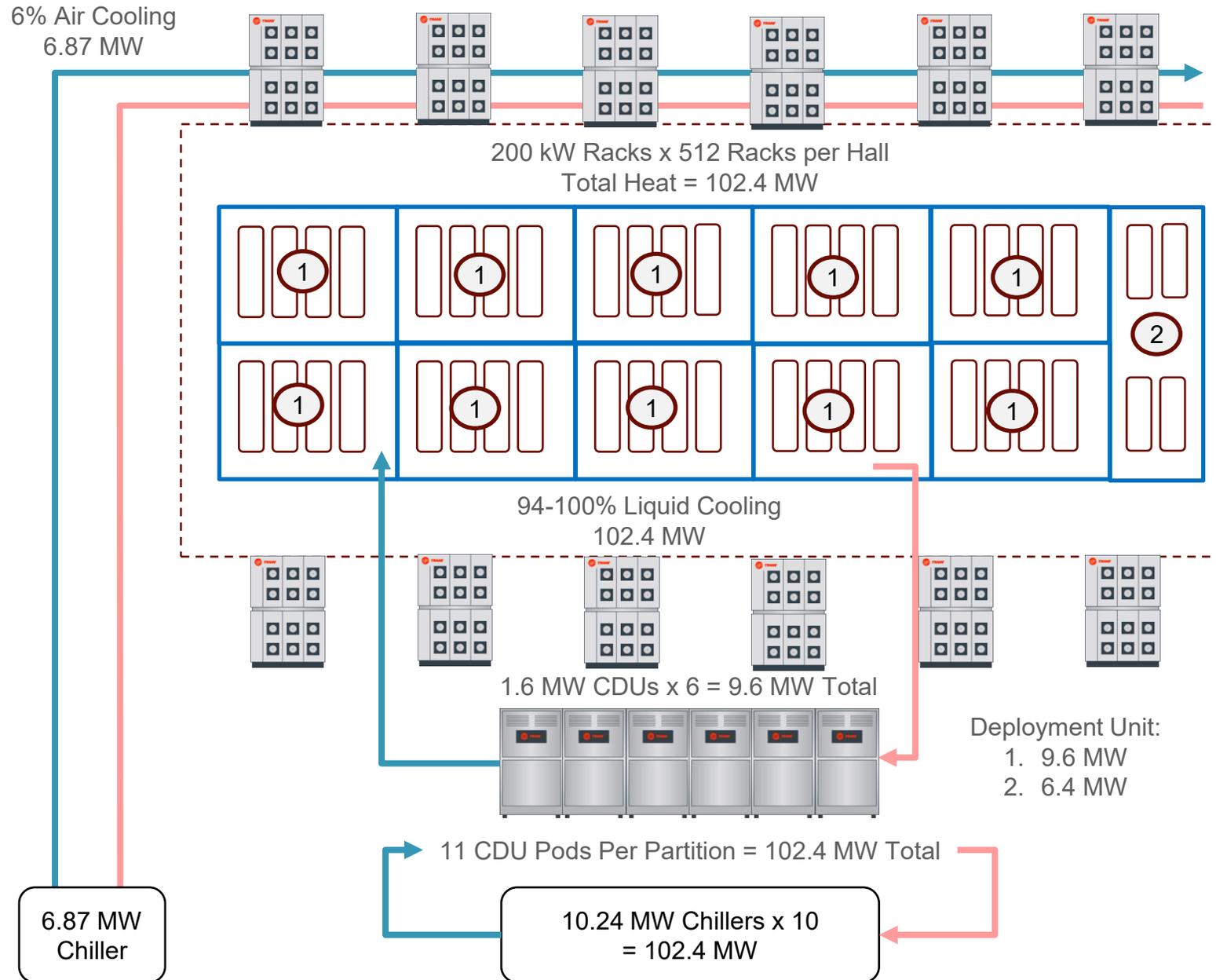
CenTraVac® Water-Cooled Multi-Mode Chillers (Model CVHH)
Swing Plant Provides Redundancy For Either Temperature Loop

BEST PRACTICES

Block Sizing

Designing a single chiller plant for a 1 GW data center isn't practical due to the massive pipe, valve, and pump sizes required. A better solution is to divide the load into 102.4 MW partitions, typically using 48-inch piping based on system design.

- Each partition is served by 10 - 9.6 MW CDU pods and 1 - 6.4 MW CDU pod
- Each CDU has N+1 Redundancy
- Each totals 102.4 MW and includes 512 (200-kW) racks.
- 9.6 MW Deployment : 4 rows, 12 *200-kW racks per row
- 6.4 MW Deployment: 4 rows, 8 *200-kW racks per row
- Remaining site power reserved for airside cooling loop, additional IT loads and other site needs



→ **BEST PRACTICES**

Freeze Protection

Outdoor equipment such as dry coolers and exposed piping is at risk of freezing when ambient temperatures drop below the fluid's freeze point. Protection can be achieved by selecting a suitable fluid or by adding heat to maintain temperature above freezing.

- Select a fluid with a freeze point below expected operating conditions
- Add heat to keep local temperatures above the fluid's freeze point

Glycol solutions (propylene or ethylene) have a freeze point, where crystals begin to form, and a burst point, where expansion can cause damage. Proper concentration ensures the fluid remains pumpable and prevents freezing under site conditions.

If water is used, heat must be added when the heat-rejection load is insufficient to keep the temperature above freezing—especially in heat-rejection devices such as dry coolers. The amount of heat required depends on ambient conditions, water volume, and insulation quality.

If glycol is undesirable in the full loop, install isolation heat exchangers and local pumps to confine glycol to small closed loops while maintaining protection for any connected water lines.

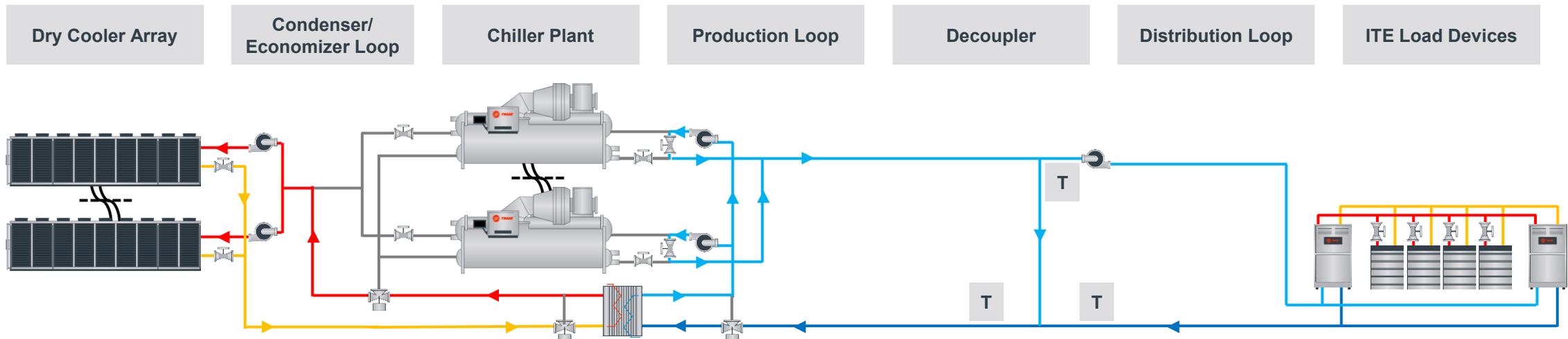
→ BEST PRACTICES

Decoupled Loops

Separating the production (chiller) and distribution loops allows each to operate at its optimal temperature difference (ΔT), helping to improve efficiency and control while reducing pump energy. The decoupled design also simplifies system staging and enhances overall plant stability.

- Production and distribution loops operate independently to optimize flow and ΔT
- Pump energy consumption is reduced under varying load conditions
- Flow through the decoupler indicates plant balance and triggers chiller staging
- The design provides smoother operation and faster response to load changes

Typical Decoupled Plant



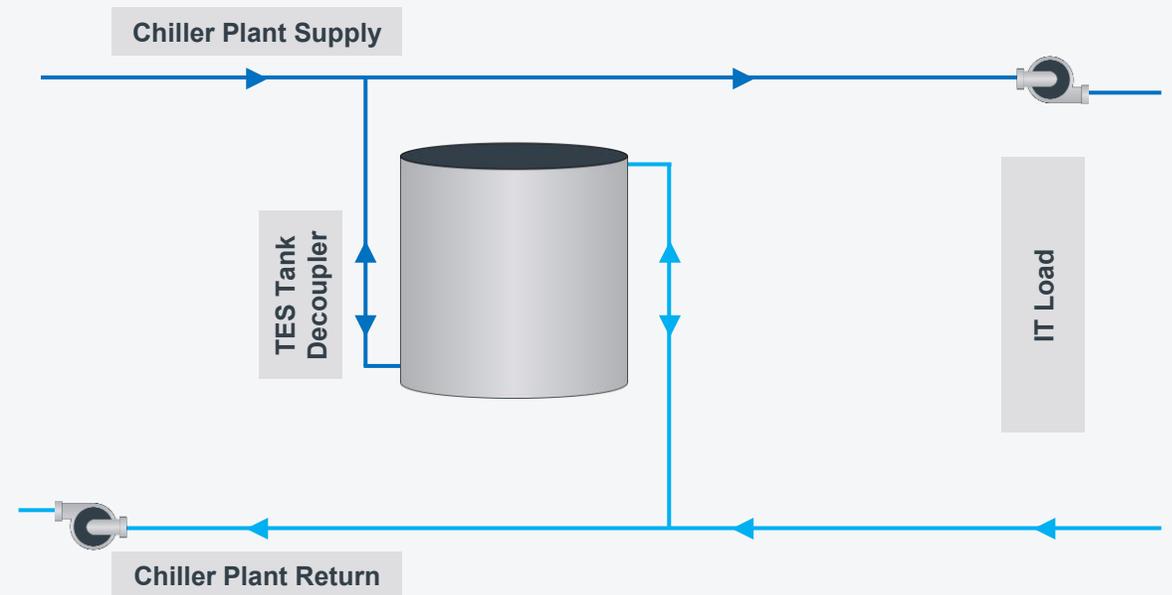
→ BEST PRACTICES

Thermal Energy Storage

Thermal storage can be added to the chiller plant in various ways, with tank placement based on system needs.

- **Tank in the decoupler line.** Placing the tank in the decoupler line provides all the noted benefits and lets it function as a thermal battery—charging when production exceeds demand and discharging when demand is higher. System controls can optimize this cycle throughout the day.
- **Tank on return side.** Placing the tank on the return side helps absorb rapid temperature swings, keeping return water stable and allowing chillers to maintain consistent leaving-water temperatures.

Thermal storage tank in the decoupler pipe



→ **SYSTEM CONTROLS**

Effective controls are critical to chiller plant performance and reliability. Trane's data center-specific control platform promotes efficiency, uptime and responsiveness by integrating all major components — chillers, dry coolers, pumps, valves, CDUs and fan coil walls — into one coordinated system.



SYSTEM CONTROLS

Reference Diagram

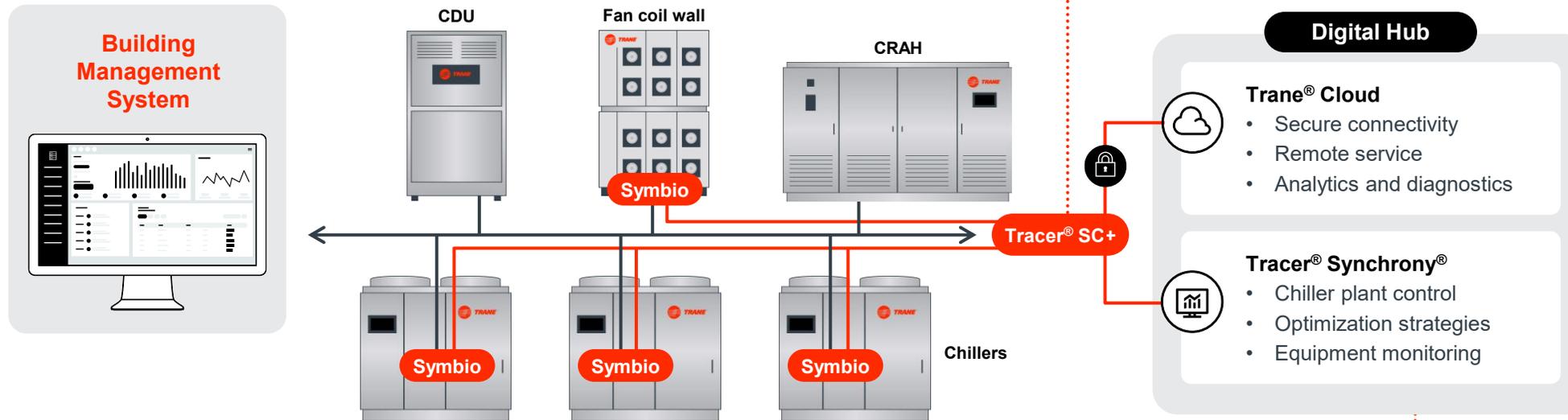
System Control

Tracer® is a unified thermal management system that simplifies operations by handling chiller rotation, staging, and sequencing with built-in tools that boost reliability and enable data-driven performance.

AI Enhancements

Take optimization further with our AI-driven efficiency engine. **Trane® AI Control** blends decades of expertise with real-time data to continuously improve your thermal management system and capture every possible watt of savings.

Trane Thermal Management System



Insights + Optimization

When power is limited, your cooling system must run at peak efficiency—every kilowatt saved means more racks online. **Trane Intelligent Services** uses whole-system data to deliver actionable energy-saving strategies.

Equipment Connectivity

Symbio® controls collect and translate key equipment data into the **Tracer SC+**, enabling data-driven service and optimization.

Predictive Maintenance

With your permission, we can securely connect to your equipment or Tracer SC+ to enable **Connected Mechanical Service**. By monitoring trends and performance data, we help identify issues early so your team or our technicians can act before failures occur. And when on-site support is needed, **Trane Service Agreements** and **local technicians** are ready to respond.



TRANE SERVICE

As data centers expand in size and complexity, the need for dependable, efficient cooling grows with them. Trane's thermal management services are designed to meet these evolving demands — providing scalable, responsive support that adapts to changing loads, tighter schedules and zero-tolerance uptime requirements.

- Embedded expertise ensures reliable operation from design through expansion and refresh
- Proactive planning helps reduce risk and downtime
- Connected insights help optimize capacity and efficiency across the lifecycle



→ TRANE RENTAL SERVICES

Need unrivaled temporary thermal management and power solutions for your data center? Trust Trane Rental Services for:

- Level 2, 3, and 4 **commissioning services**, including line flushes and load bank testing
- **Expansion and retrofits** for new chip designs
- Planned **maintenance, emergency response, and redundancy** to protect SLAs
- Overcoming **new equipment lead times** to speed up new facility launches

As one of North America's largest OEM HVAC rental companies, Trane Rental Services leads the market. Our highly trained staff, rapid emergency response, and unmatched expertise are supported by 150 locations, 230 parts centers, and 2,600 technicians. Choose Trane Rental Services for reliable, expert solutions.



→ DESIGN RESOURCES

Trane provides a complete suite of resources to support the design of high-performance thermal management systems for data centers.

- All mechanical components are selected for site-specific conditions, with detailed submittal packages available
- System control sequences and operating modes can be customized for any chiller plant configuration
- TRACE™ modeling tools evaluate annual energy performance and efficiency
- Application guides and Trane experts are available to assist with design, optimization and implementation

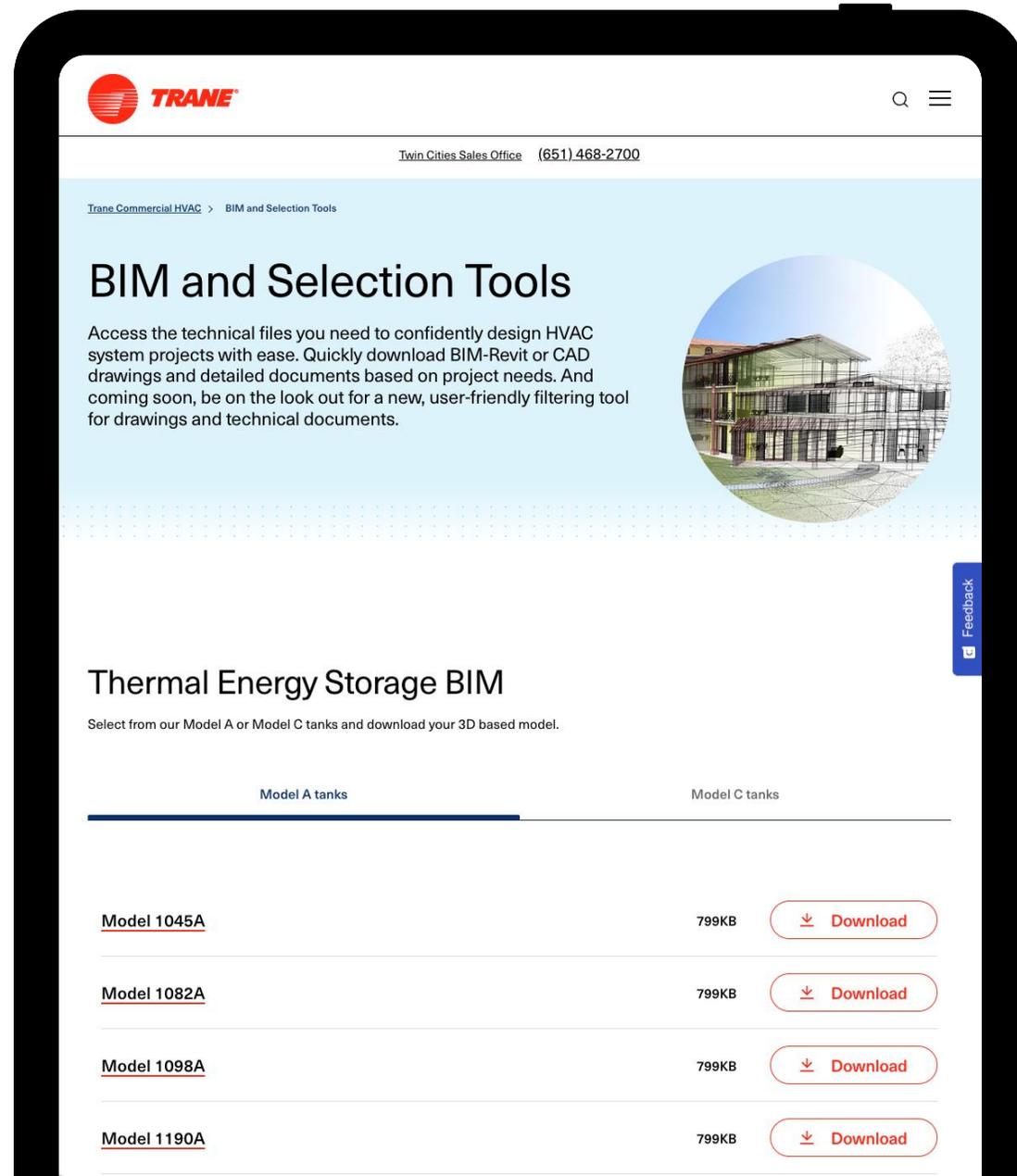
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