Chilled-Water Systems

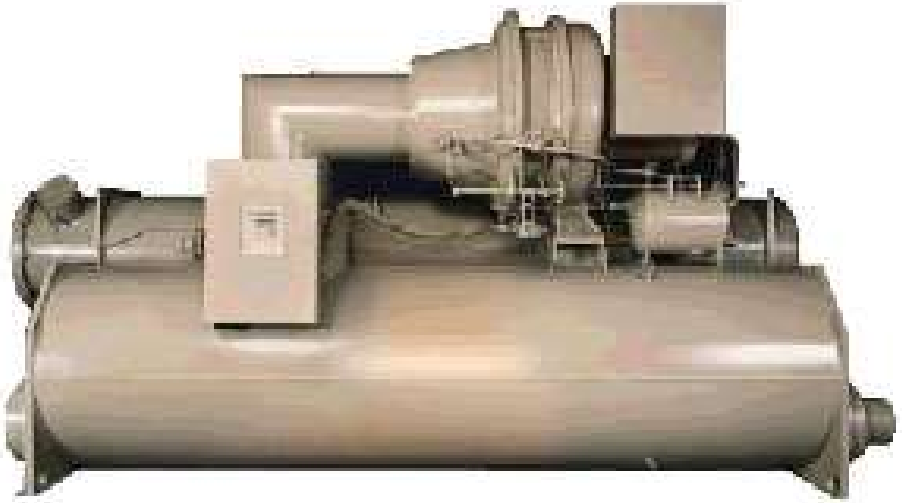
A Trane Air Conditioning Clinic

Chilled-Water Systems

period one

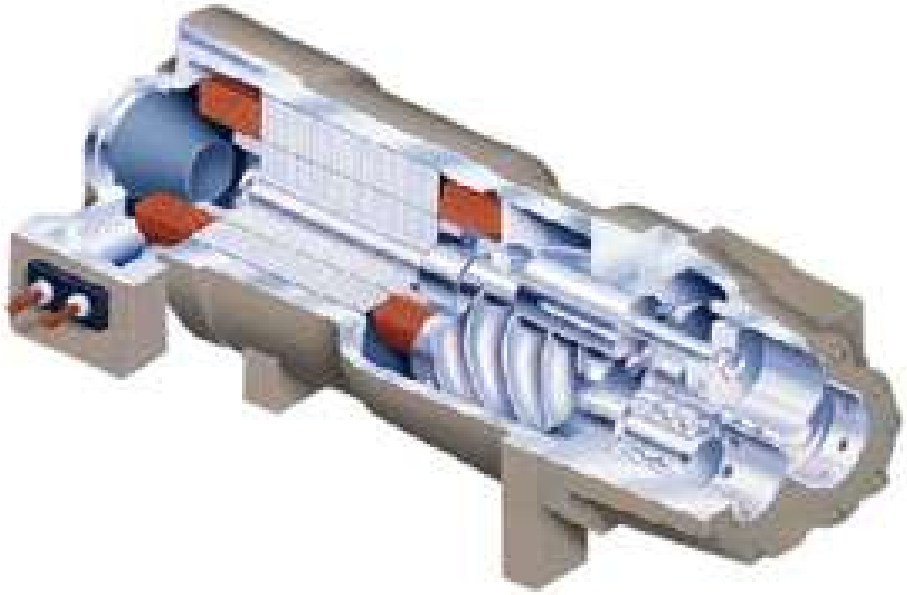
Types of Water Chillers

absorption
water chiller



centrifugal
water chiller

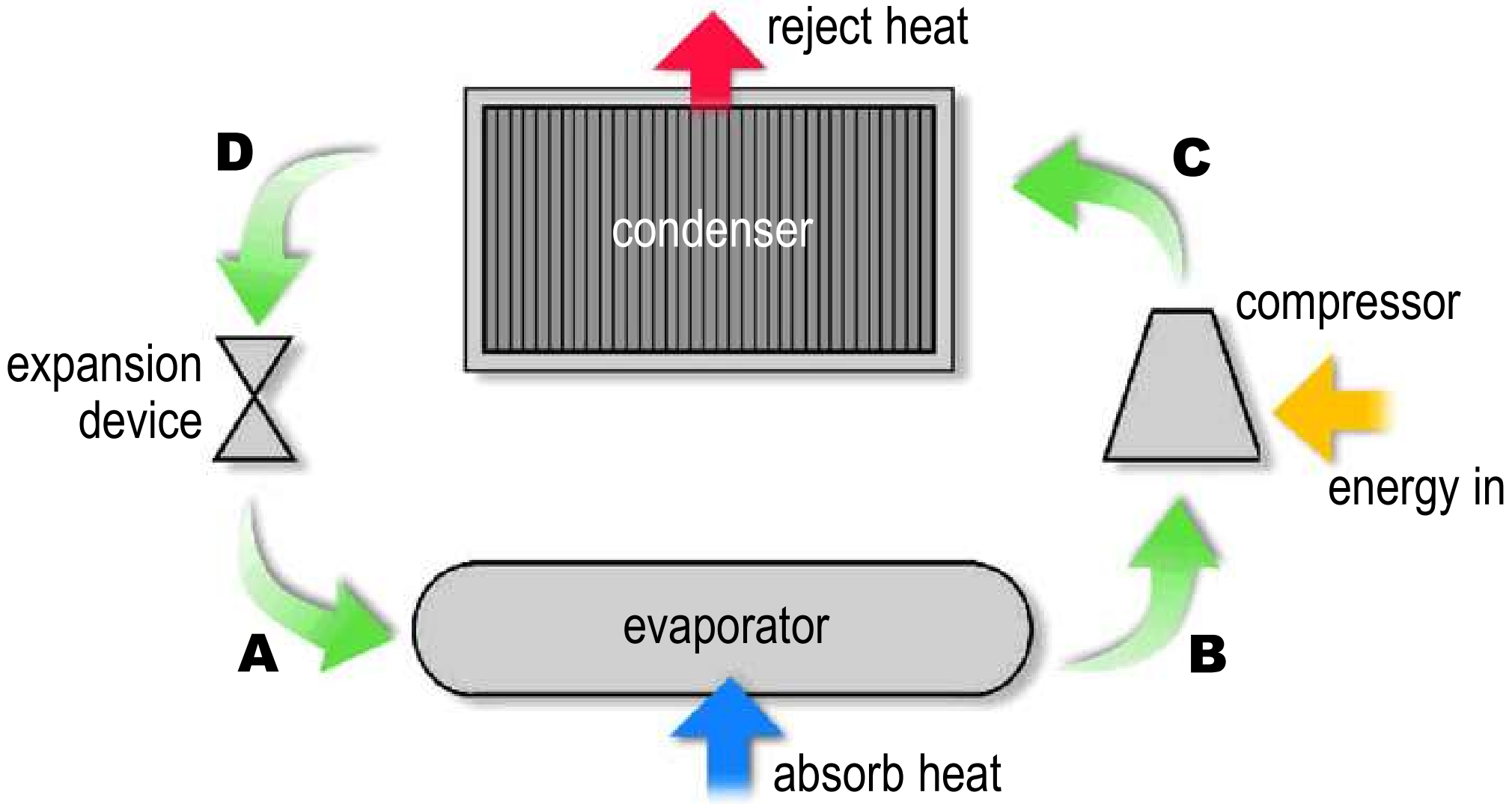
Driving Sources



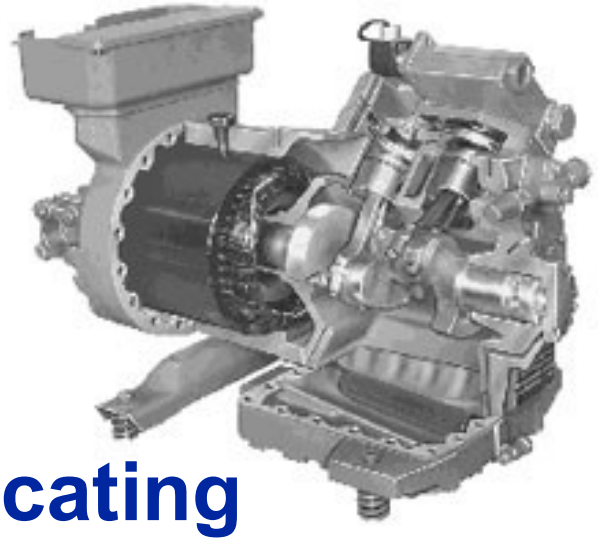
compressor-driven

heat-driven

Vapor-Compression Cycle

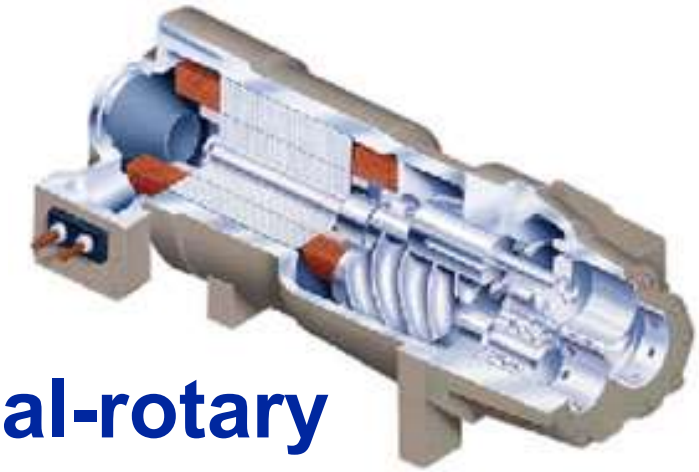


Compressor Types



reciprocating

scroll



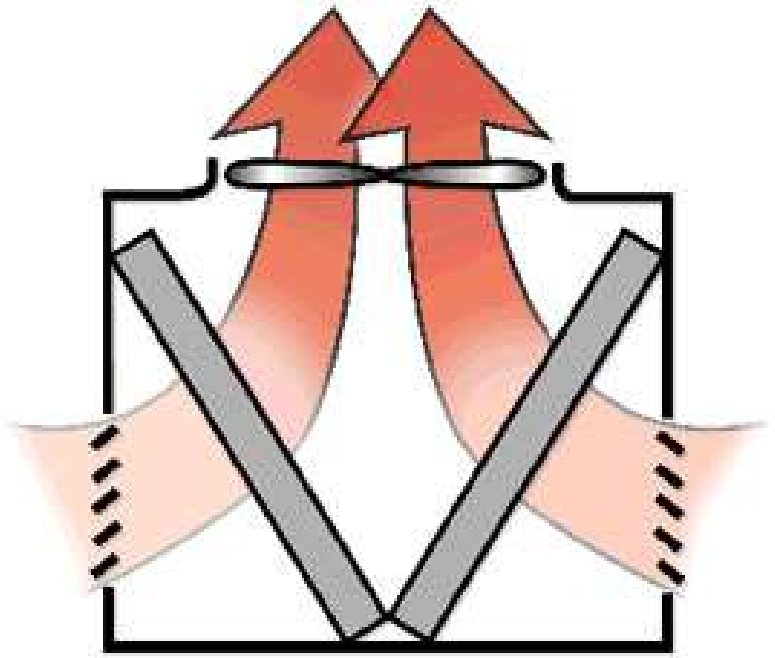
helical-rotary

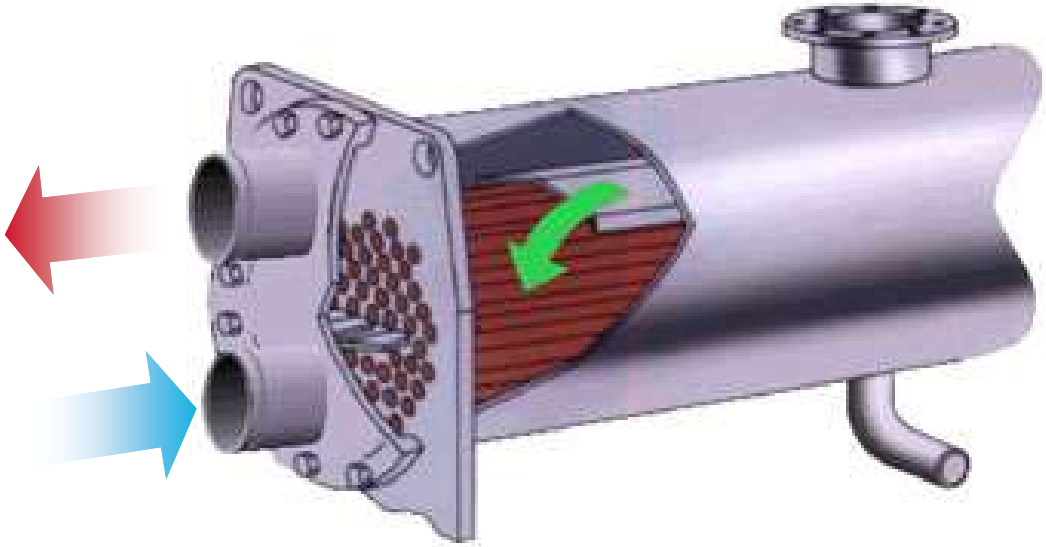
centrifugal

Variable-Speed Drives

Condenser Types

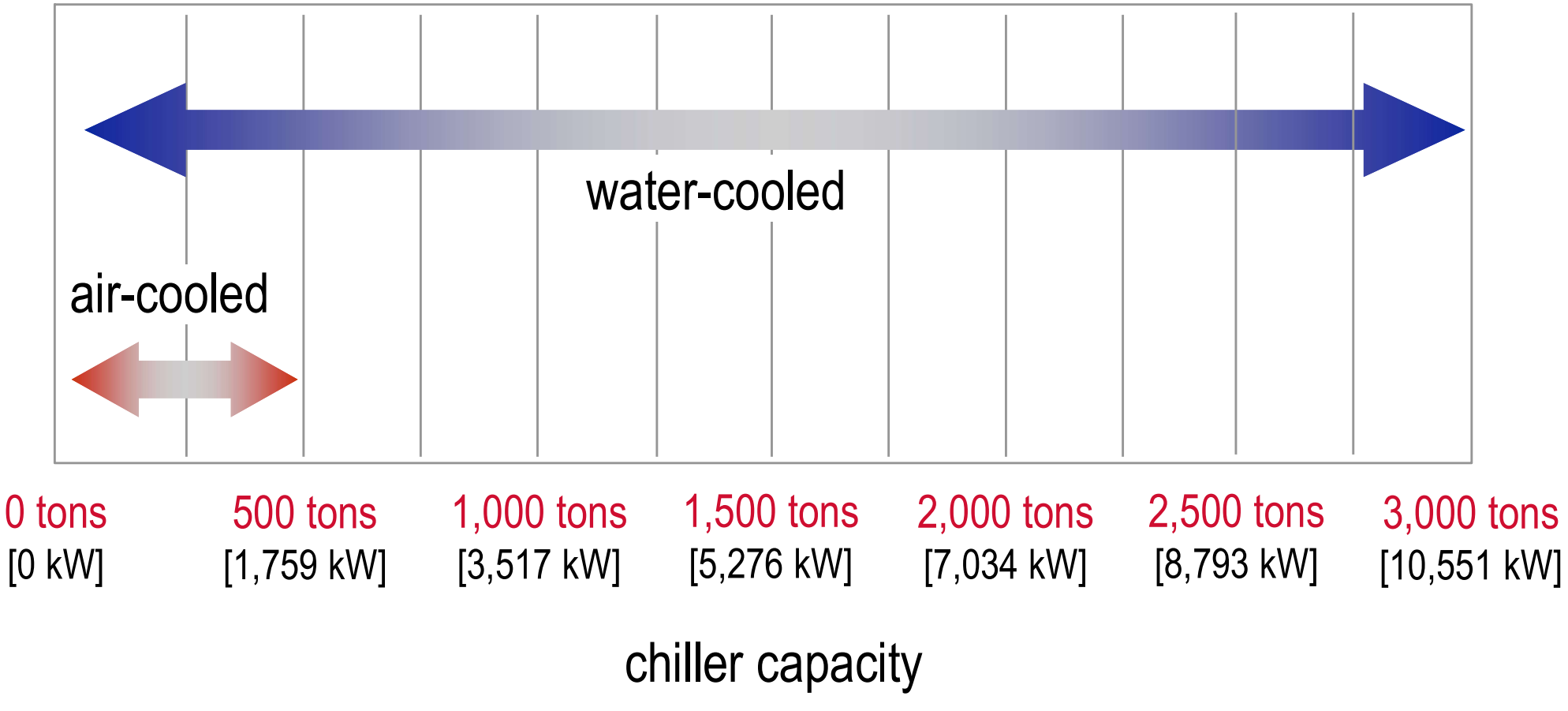
air-cooled





water-cooled

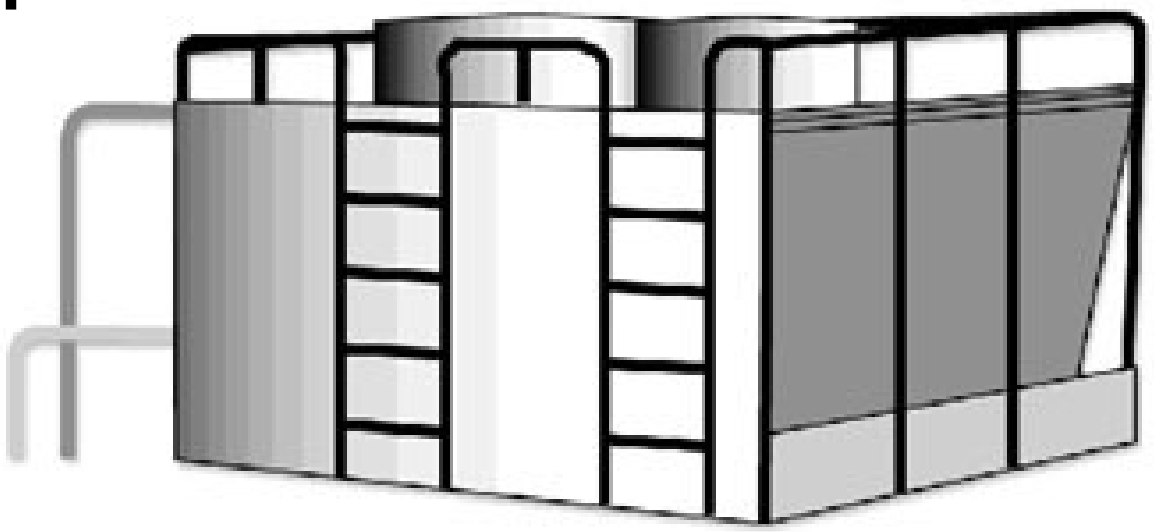
Air-Cooled or Water-Cooled



air-cooled or water-cooled

Maintenance

- Water treatment
- Condenser tube brushing
- Tower maintenance
- Freeze protection
- Makeup water



cooling tower

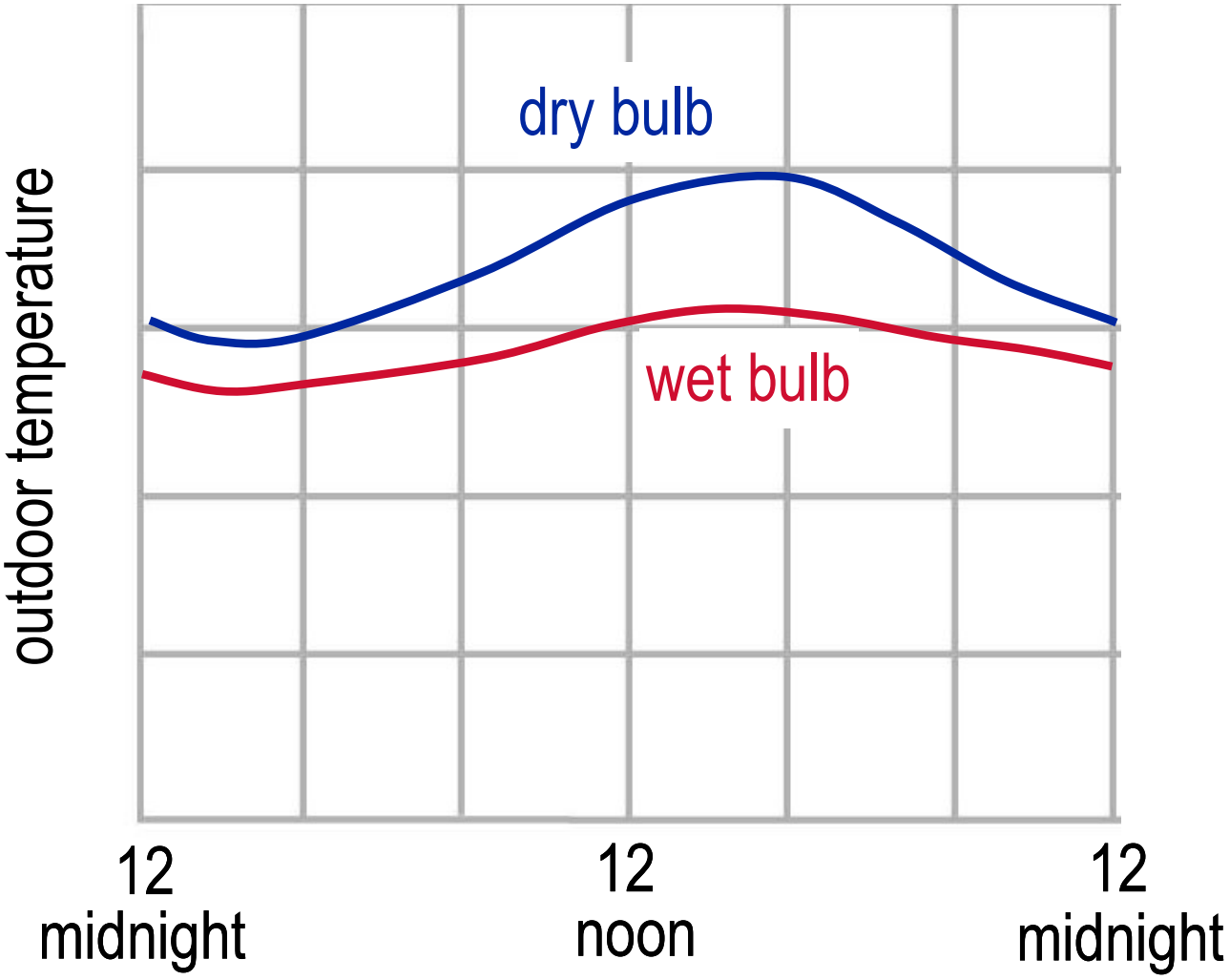
air-cooled or water-cooled

Low-Ambient Operation

air-cooled
chiller

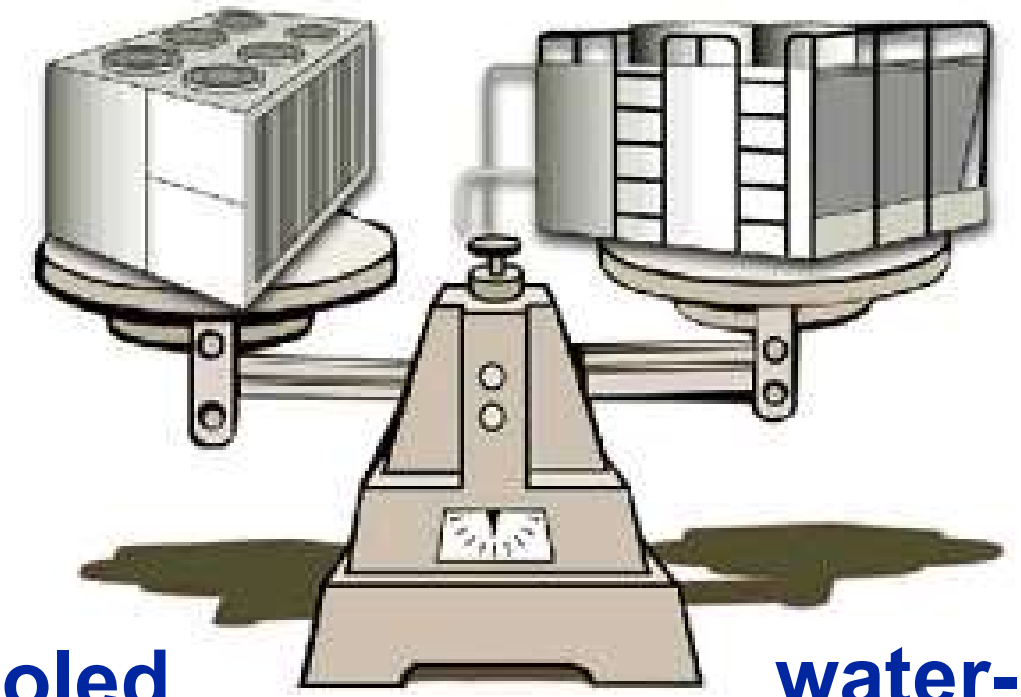
air-cooled or water-cooled

Efficiency



air-cooled or water-cooled

Comparison



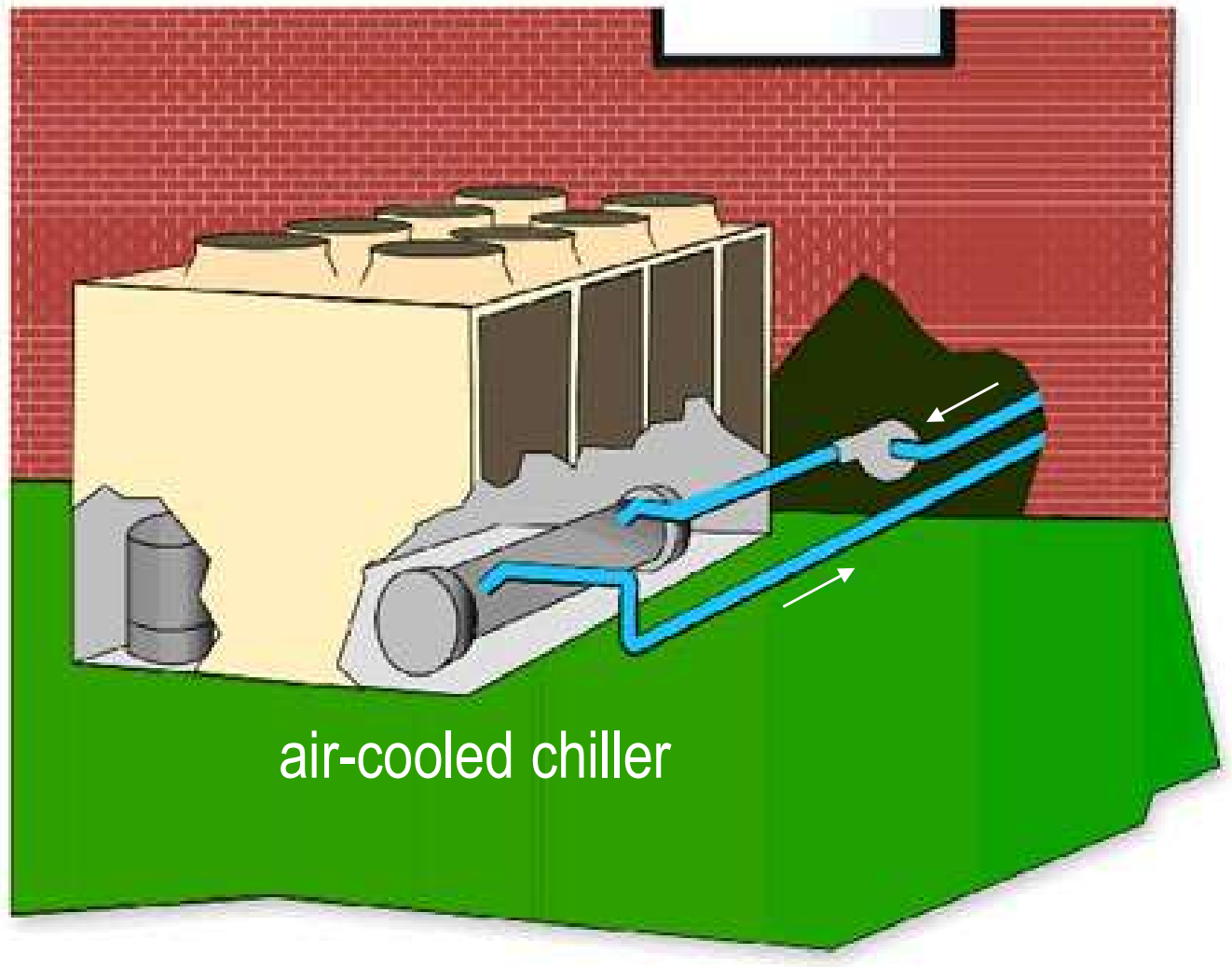
air-cooled

- Lower maintenance
- Packaged system
- Better low-ambient operation

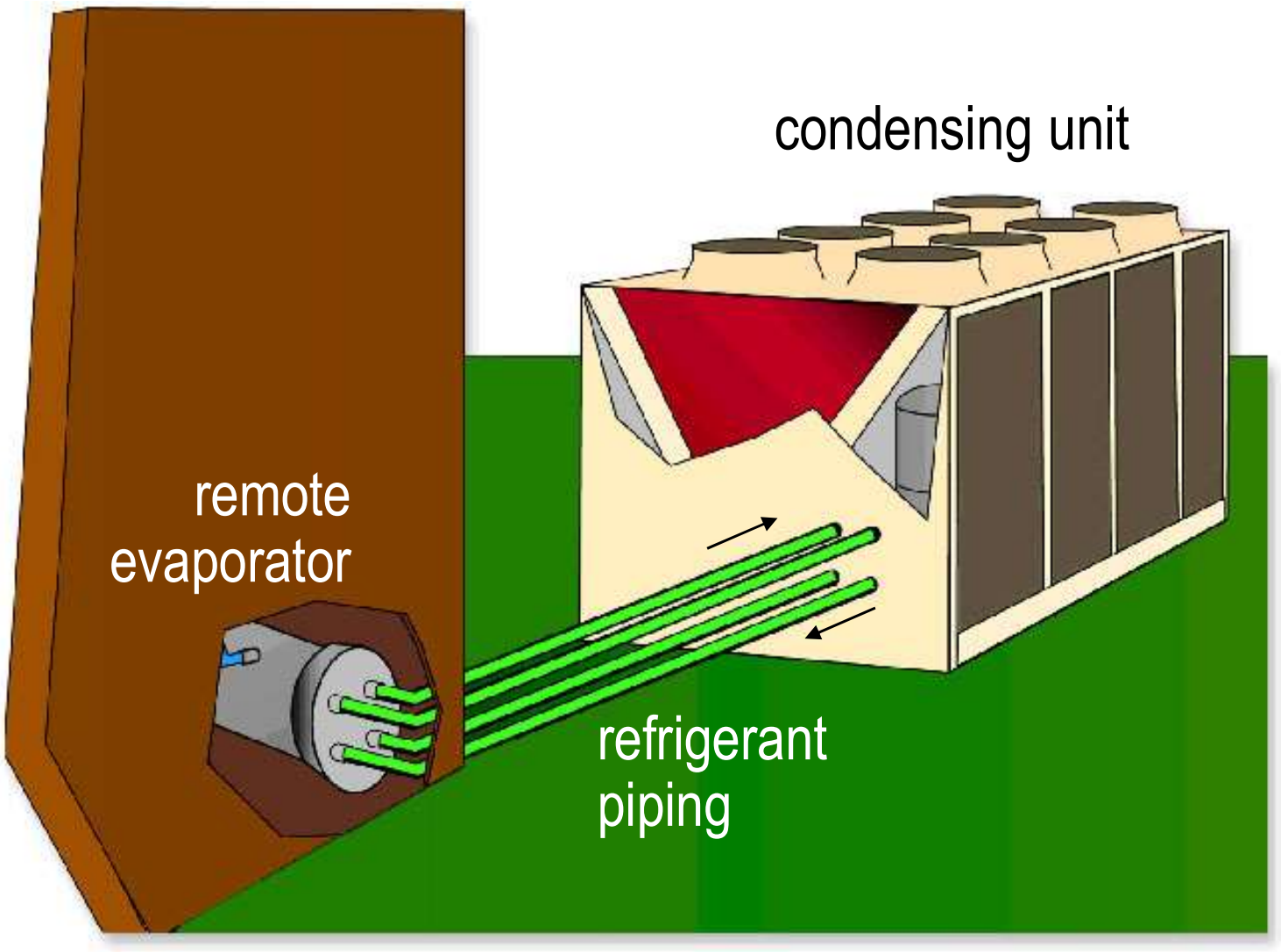
water-cooled

- Greater energy efficiency
- Longer equipment life

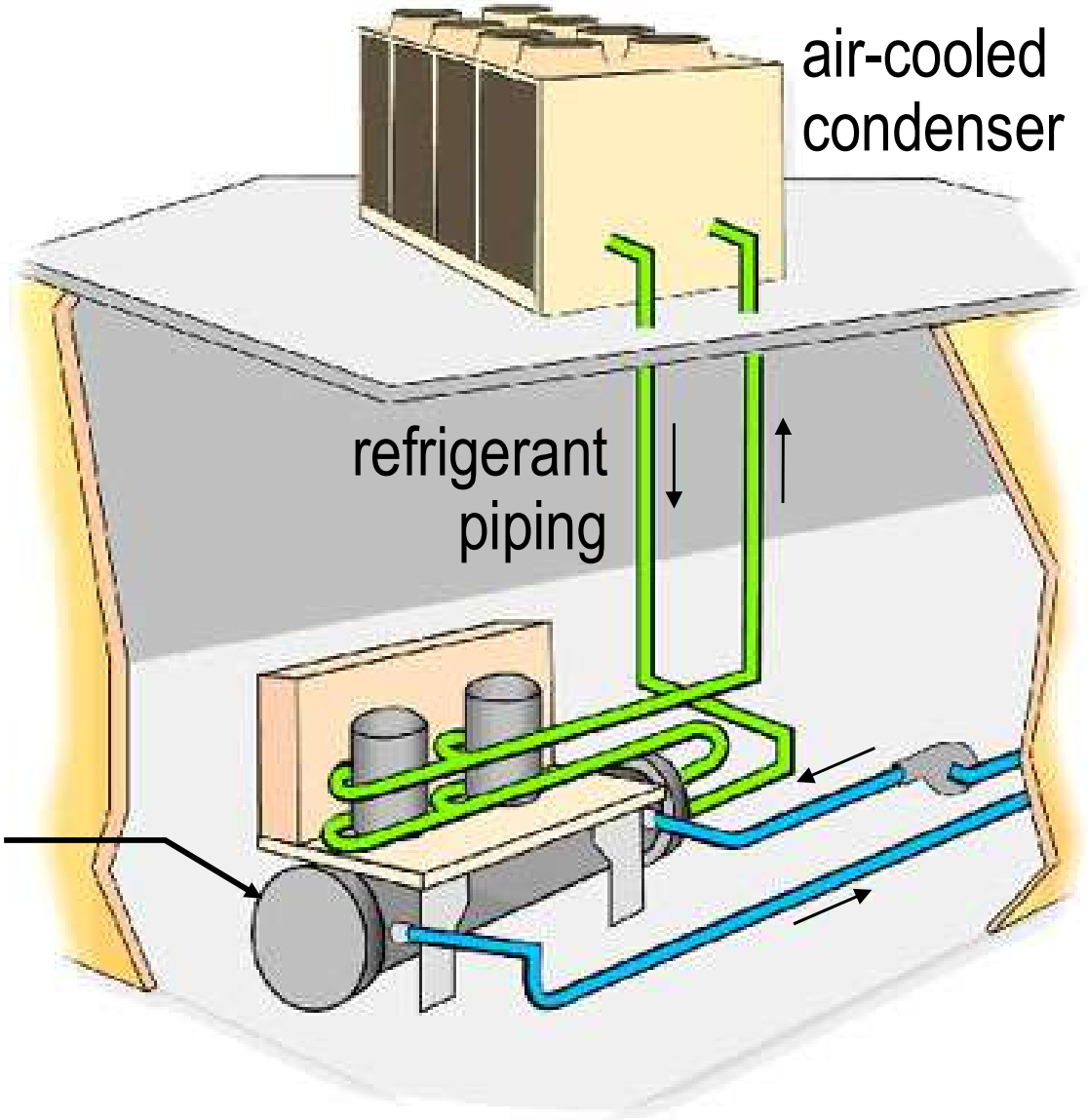
Packaged Air-Cooled Chiller



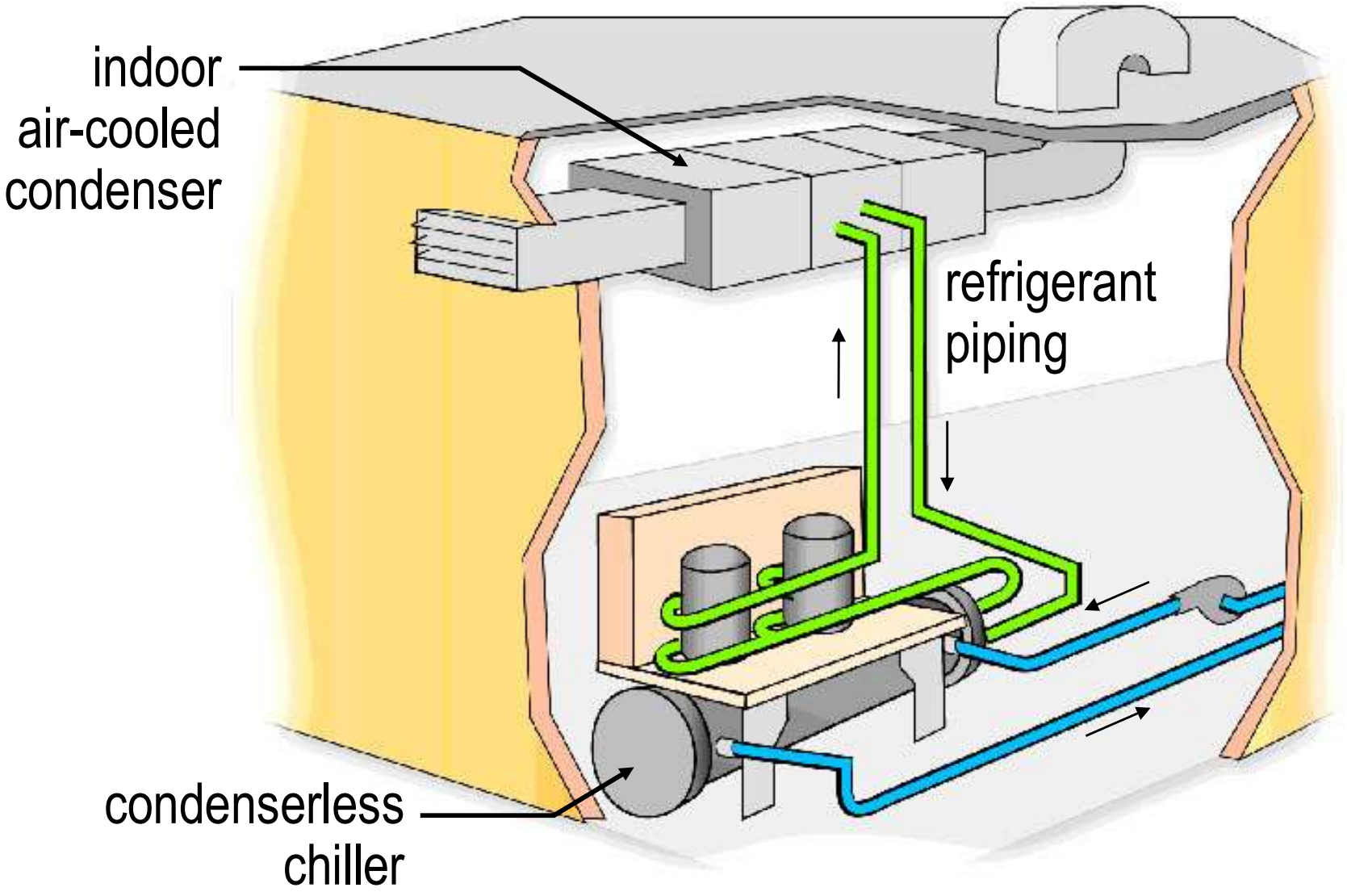
Remote Evaporator Barrel



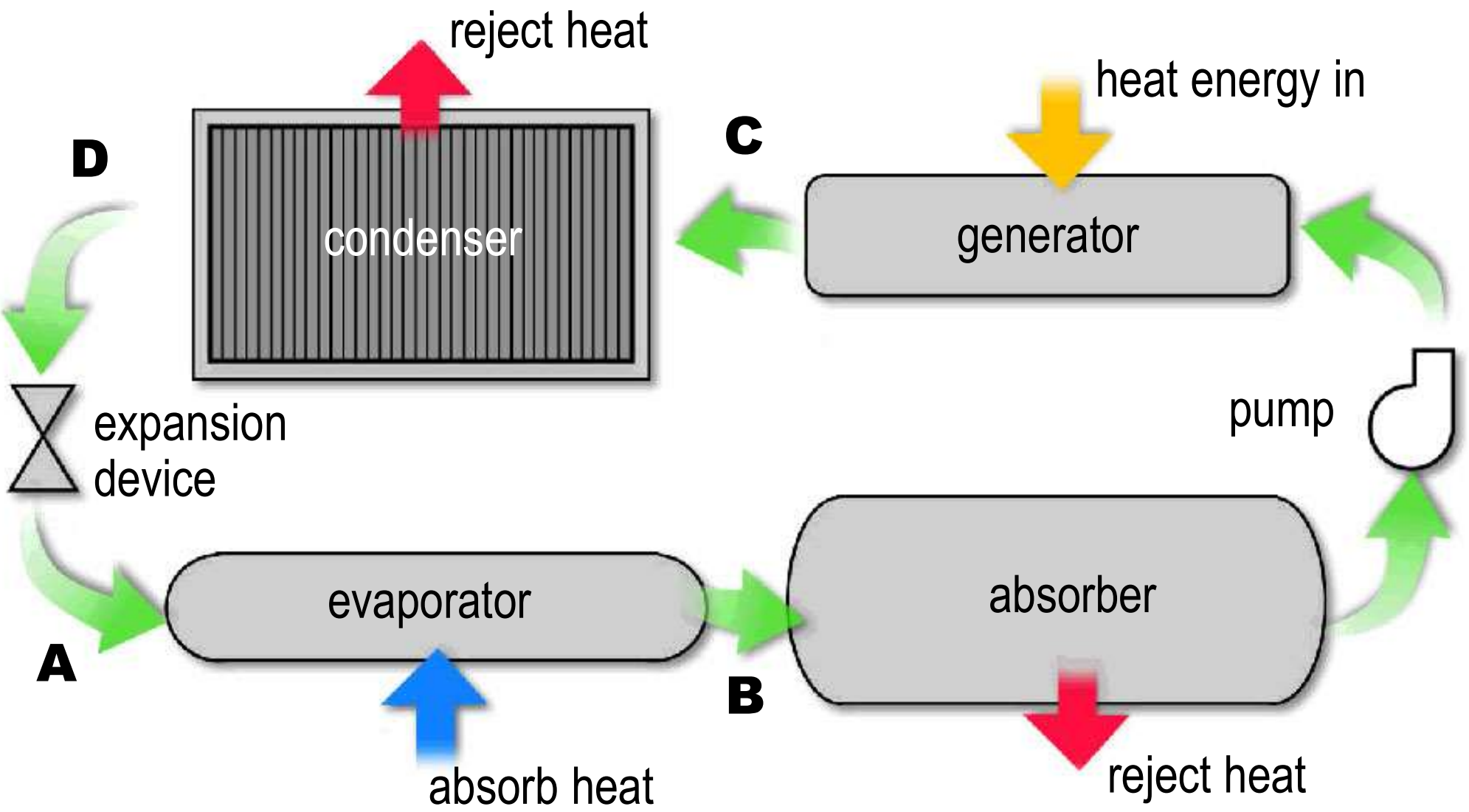
Remote Air-Cooled Condenser



Indoor Air-Cooled Condenser



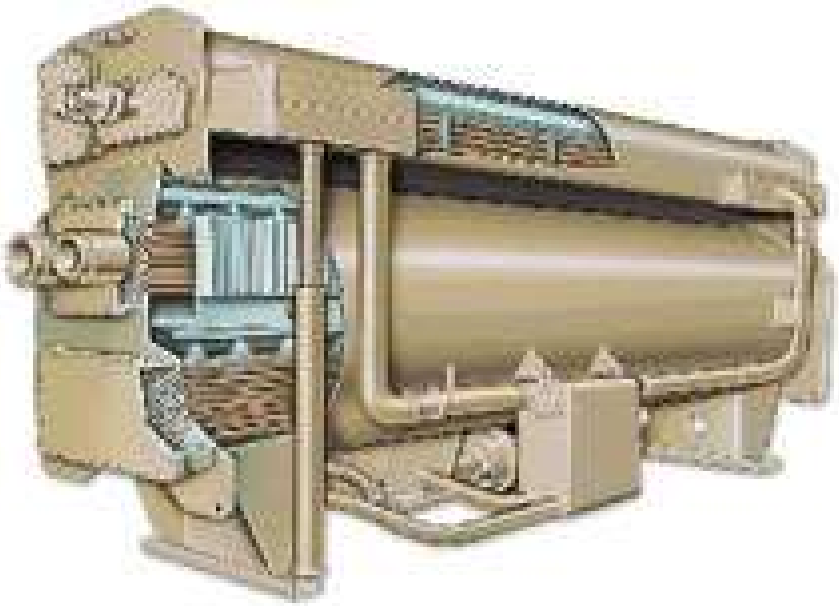
Absorption Refrigeration Cycle



Absorption Chillers Offer Choice

- Avoid high electric demand charges
- Minimal electricity needed during emergency situations
- Waste heat recovery
- Cogeneration

Absorption Chiller Types



single-effect

double-effect

direct-fired

Equipment Rating Standards

- **Air-Conditioning & Refrigeration Institute (ARI)**
  - Standard 550/590–1998: centrifugal and helical-rotary water chillers
  - Standard 560–1992: absorption water chillers

Part-Load Efficiency Rating

- **Integrated Part-Load Value (IPLV)**
  - Weighted-average load curves
  - Based on an “average” single-chiller installation
  - Standard operating conditions
- **Non-Standard Part-Load Value (NPLV)**
  - Weighted-average load curves
  - Based on an “average” single-chiller installation
  - Non-standard operating conditions

Standard Rating Conditions

chiller type	evaporator flow rate	condenser flow rate	rating standard
vapor-compression • reciprocating • scroll • helical-rotary • centrifugal	2.4 gpm/ton [0.043 L/s/kW]	3.0 gpm/ton [0.054 L/s/kW]	ARI 550/590–1998
absorption • single-effect	2.4 gpm/ton [0.043 L/s/kW]	3.6 gpm/ton [0.065 L/s/kW]	ARI 560–1992
• double-effect, indirect-fired	2.4 gpm/ton [0.043 L/s/kW]	4.0 gpm/ton [0.072 L/s/kW]	
• double-effect, direct-fired		4.5 gpm/ton [0.081 L/s/kW]	

water leaving evaporator = 44°F [6.7°C]
water entering condenser = 85°F [29.4°C]

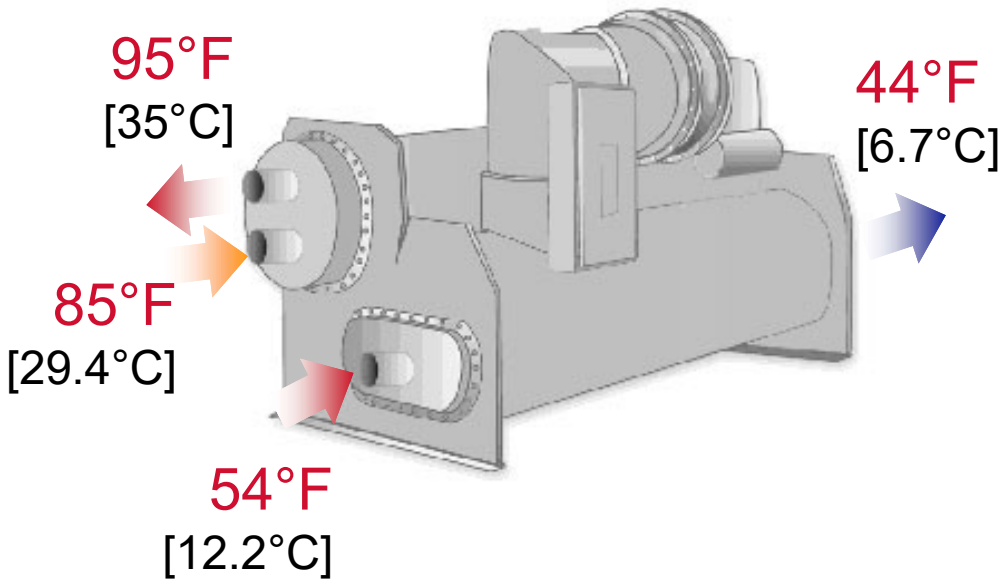
Flow Rates and Temperatures

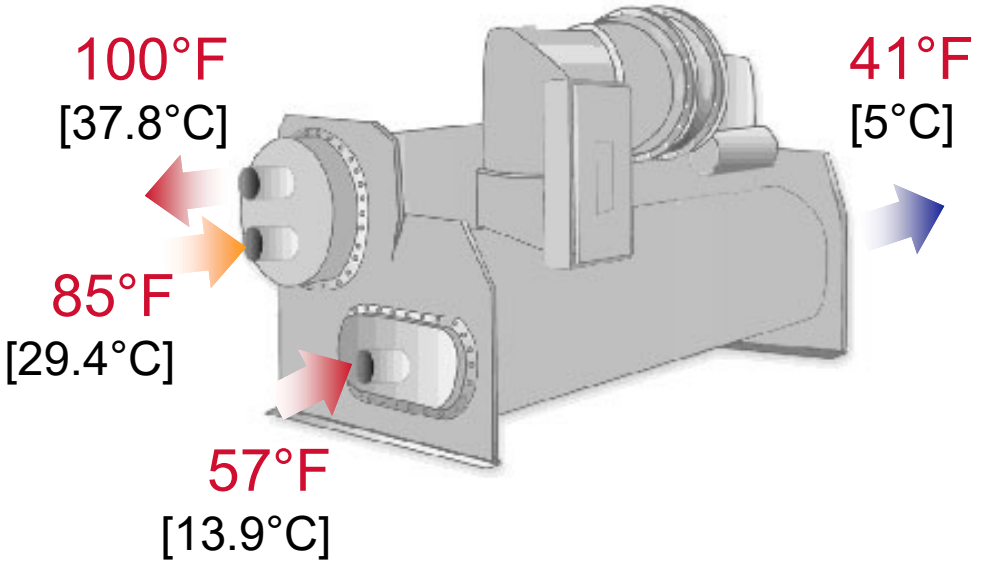
$$\mathbf{Q_{Btu/hr} = 500 \times flow\ rate \times \Delta T}$$

$$[\ Q_W = 4{,}184 \times \text{flow rate} \times \Delta T\ ]$$

equation for water only

Flow Rates and Temperatures





ARI conditions

evaporator flow rate	2.4 gpm/ton [0.043 L/s/kW]
condenser flow rate	3.0 gpm/ton [0.054 L/s/kW]

low-flow conditions

evaporator flow rate	1.5 gpm/ton [0.027 L/s/kW]
condenser flow rate	2.0 gpm/ton [0.036 L/s/kW]

ASHRAE/IESNA Standard 90.1–1999

- **Energy standard**
  - Building design and materials
  - Minimum equipment efficiencies
  - HVAC system design

standard 90.1-1999 efficiency requirements

Electric Vapor-Compression Chillers

chiller type	capacity	minimum efficiency*
air-cooled	all capacities	2.8 COP 3.05 IPLV
water-cooled		
reciprocating	all capacities	4.2 COP 5.05 IPLV
helical-rotary, scroll	< 150 tons [528 kW]	4.45 COP 5.2 IPLV
	150 to 300 tons [528 to 1,056 kW]	4.9 COP 5.6 IPLV
	> 300 tons [1,056 kW]	5.5 COP 6.15 IPLV
centrifugal	< 150 tons [528 kW]	5.0 COP 5.25 IPLV
	150 to 300 tons [528 to 1,056 kW]	5.55 COP 5.9 IPLV
	> 300 tons [1,056 kW]	6.1 COP 6.4 IPLV

* as of October 29, 2001

standard 90.1-1999 efficiency requirements

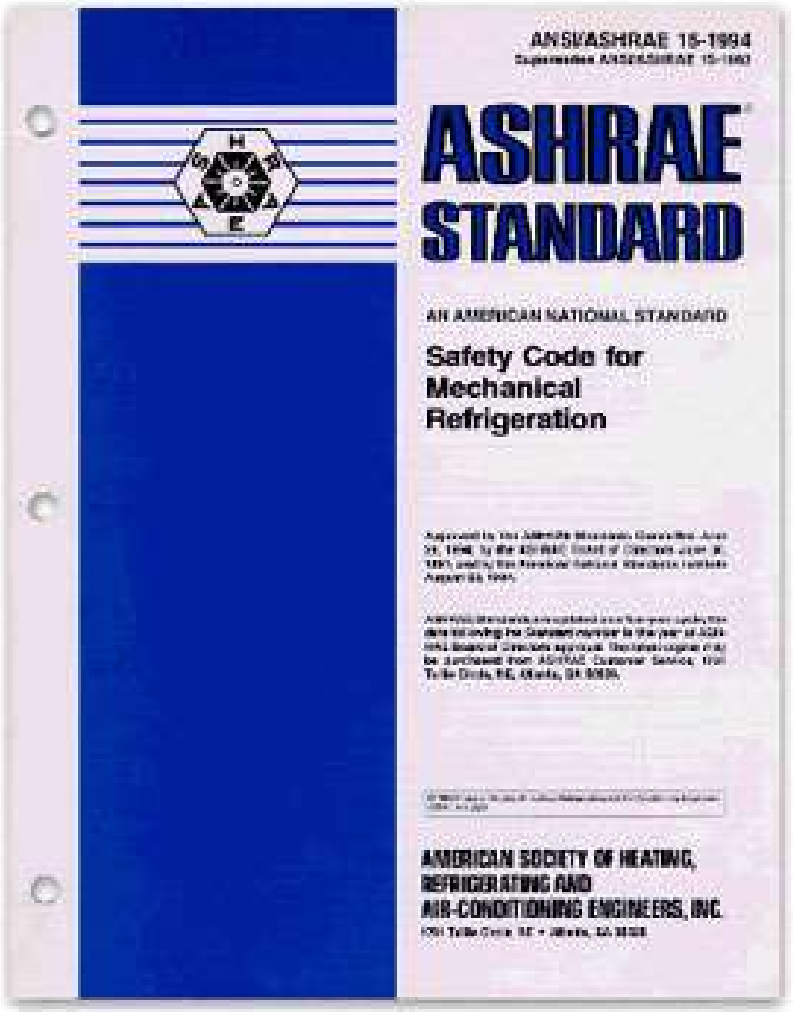
Water-Cooled Absorption Chillers

chiller type	capacity	minimum efficiency*
single-effect	all capacities	0.7 COP
double-effect		
indirect-fired	all capacities	1.0 COP 1.05 IPLV
direct-fired	all capacities	1.0 COP 1.0 IPLV

* as of October 29, 2001

ASHRAE Standard 15–1994

- **Safety standard for refrigerating systems**
- **Mechanical equipment room**
  - Refrigerant monitors
  - Alarms
  - Mechanical ventilation
  - Pressure-relief piping

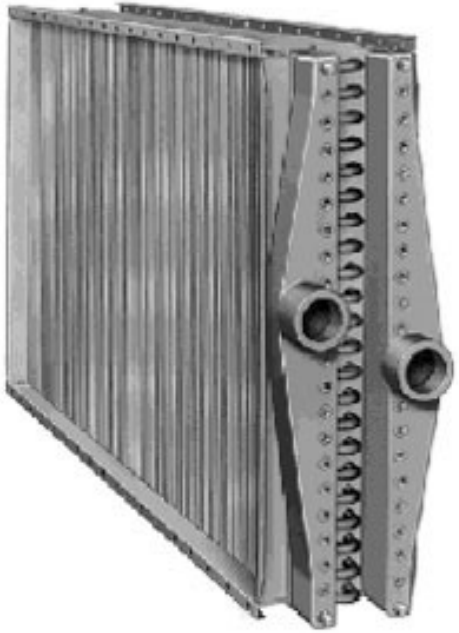


Chilled-Water Systems

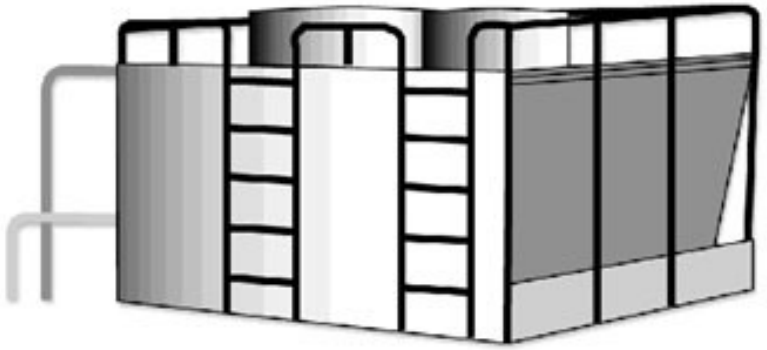
period two

Chilled-Water System Design

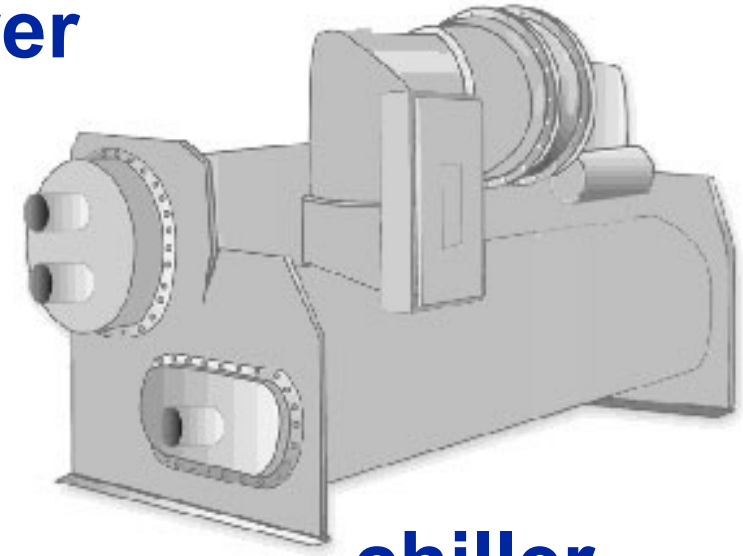
Chilled-Water System Components



cooling coil



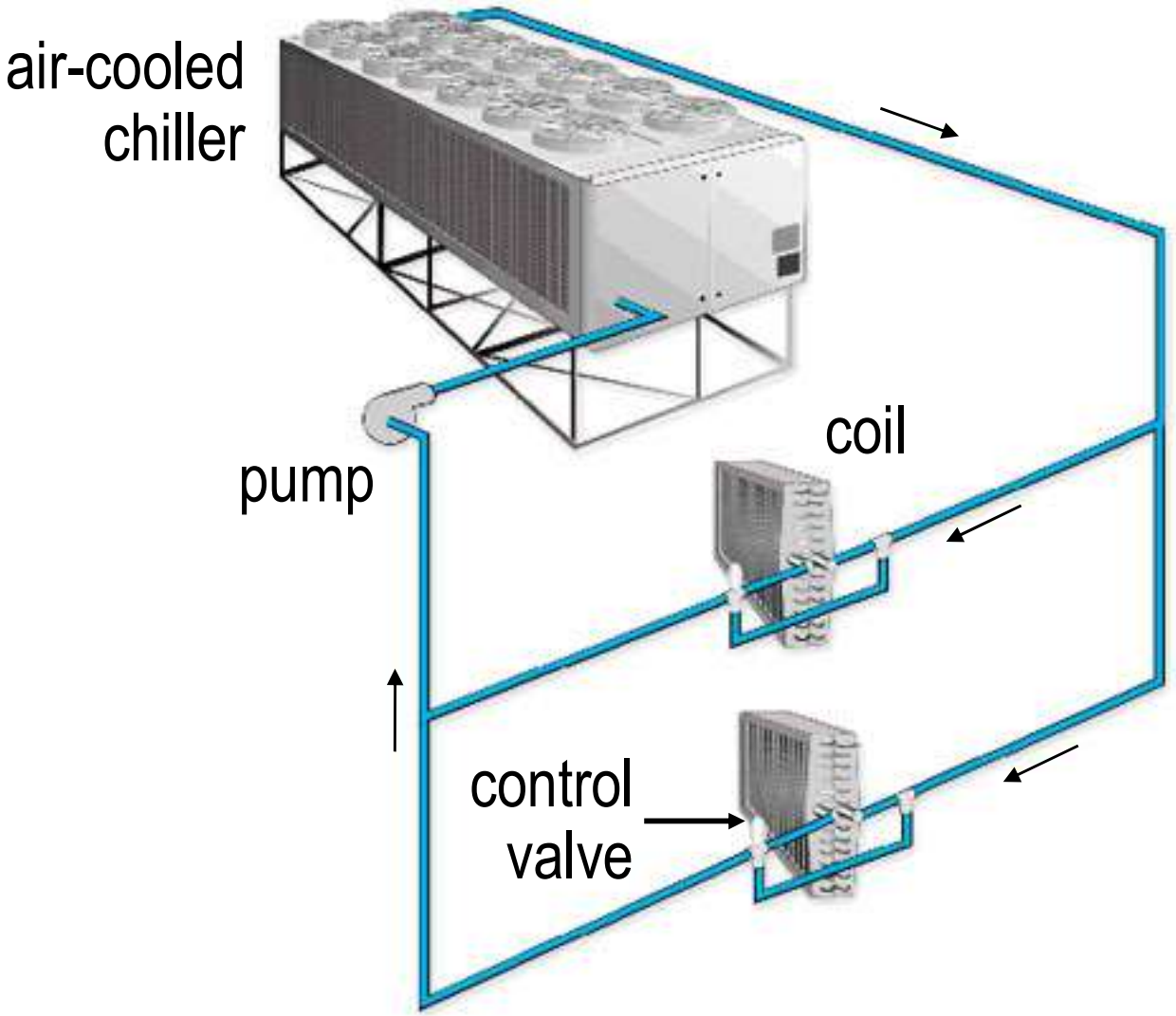
cooling tower



chiller

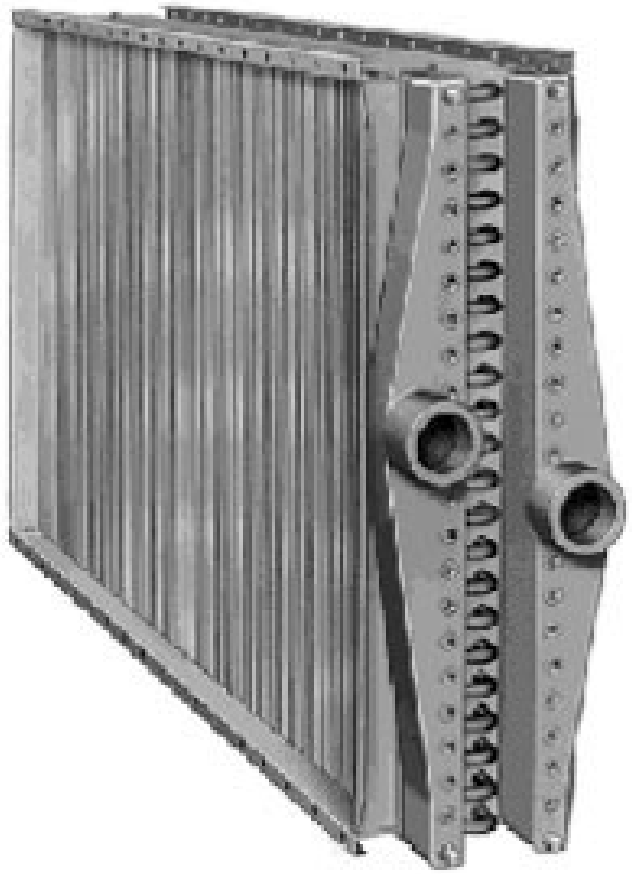
pumps

Chilled-Water System

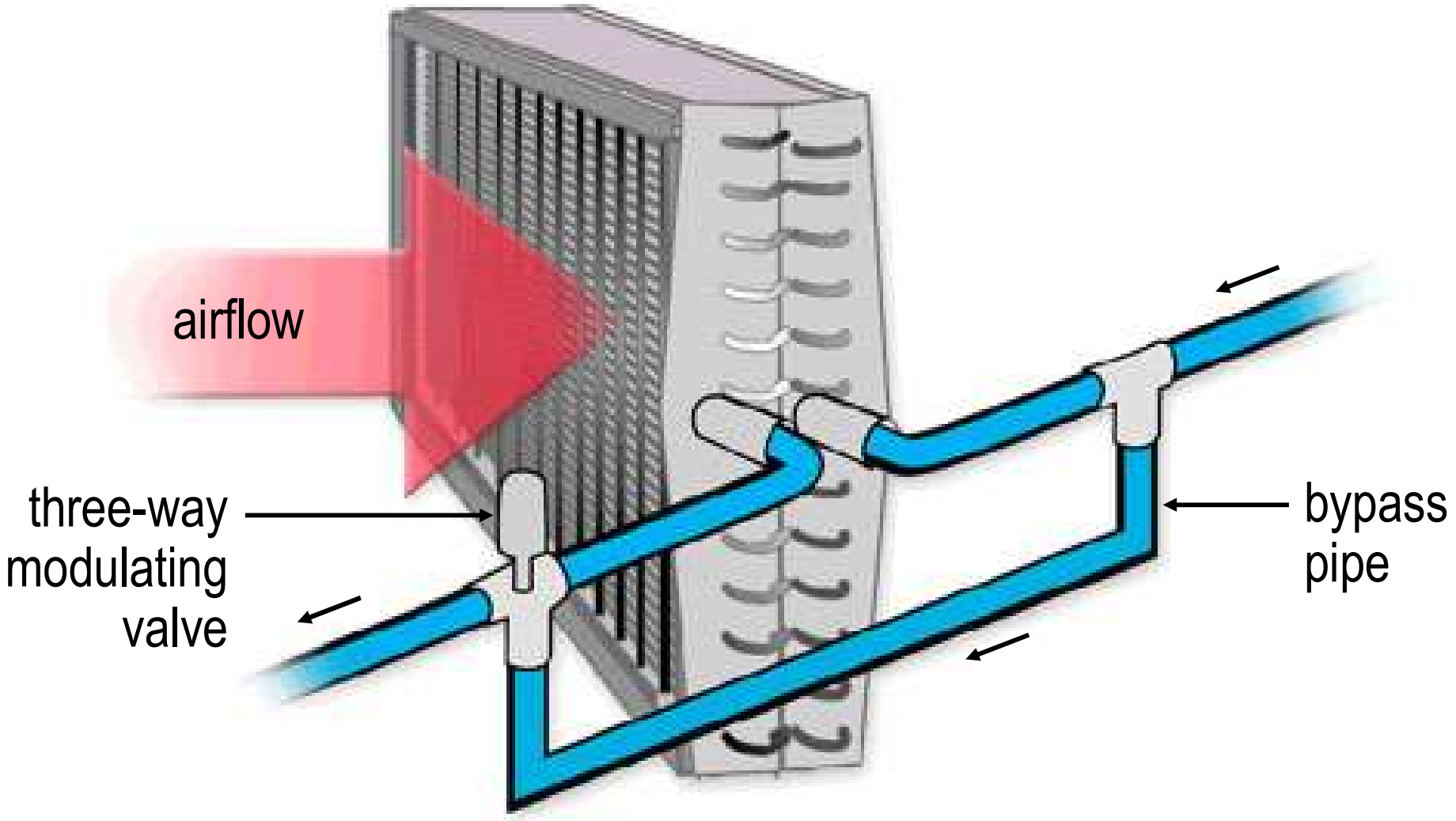


Load-Terminal Control Options

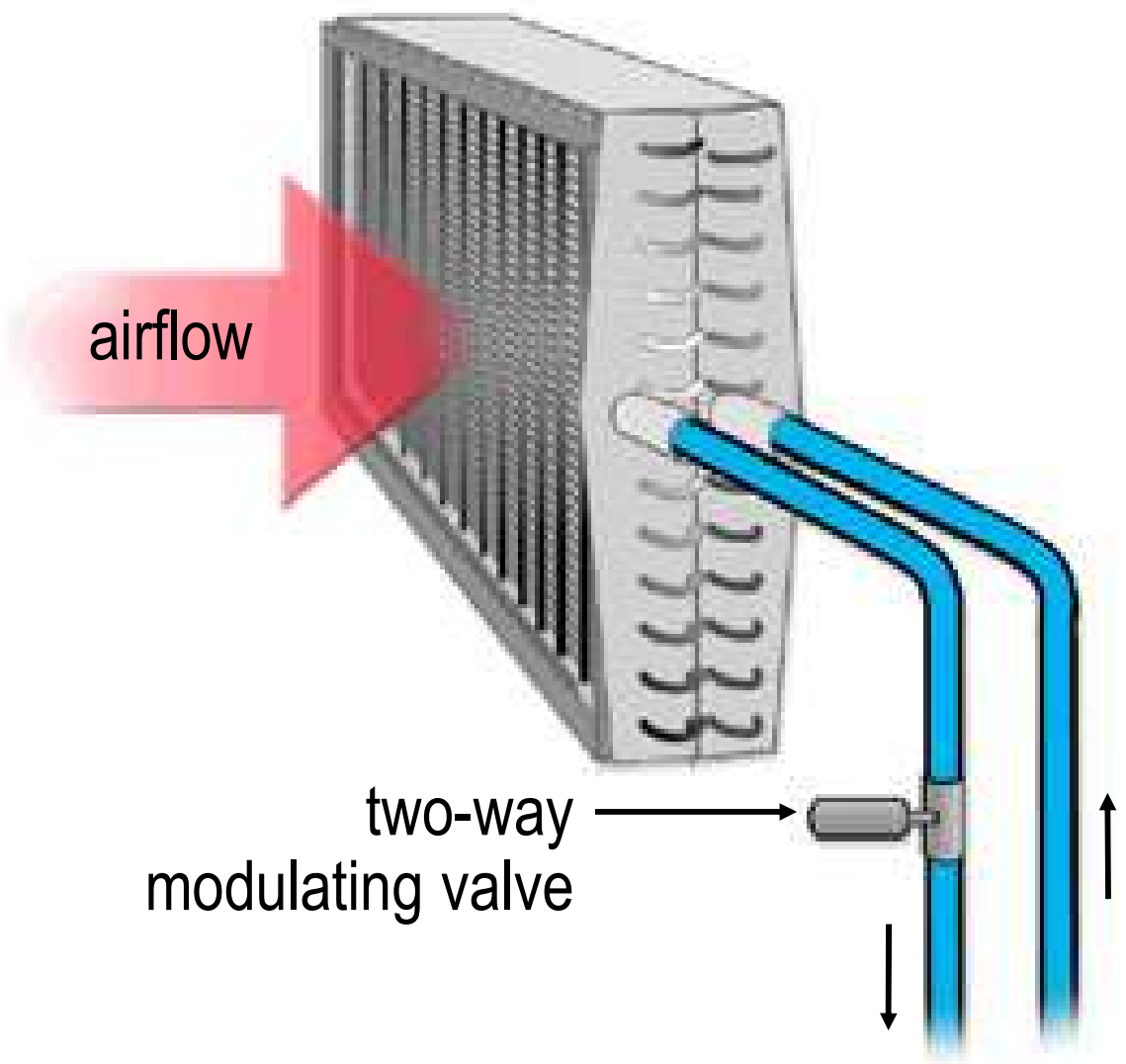
- Three-way modulating valve
- Two-way modulating valve
- Face-and-bypass dampers



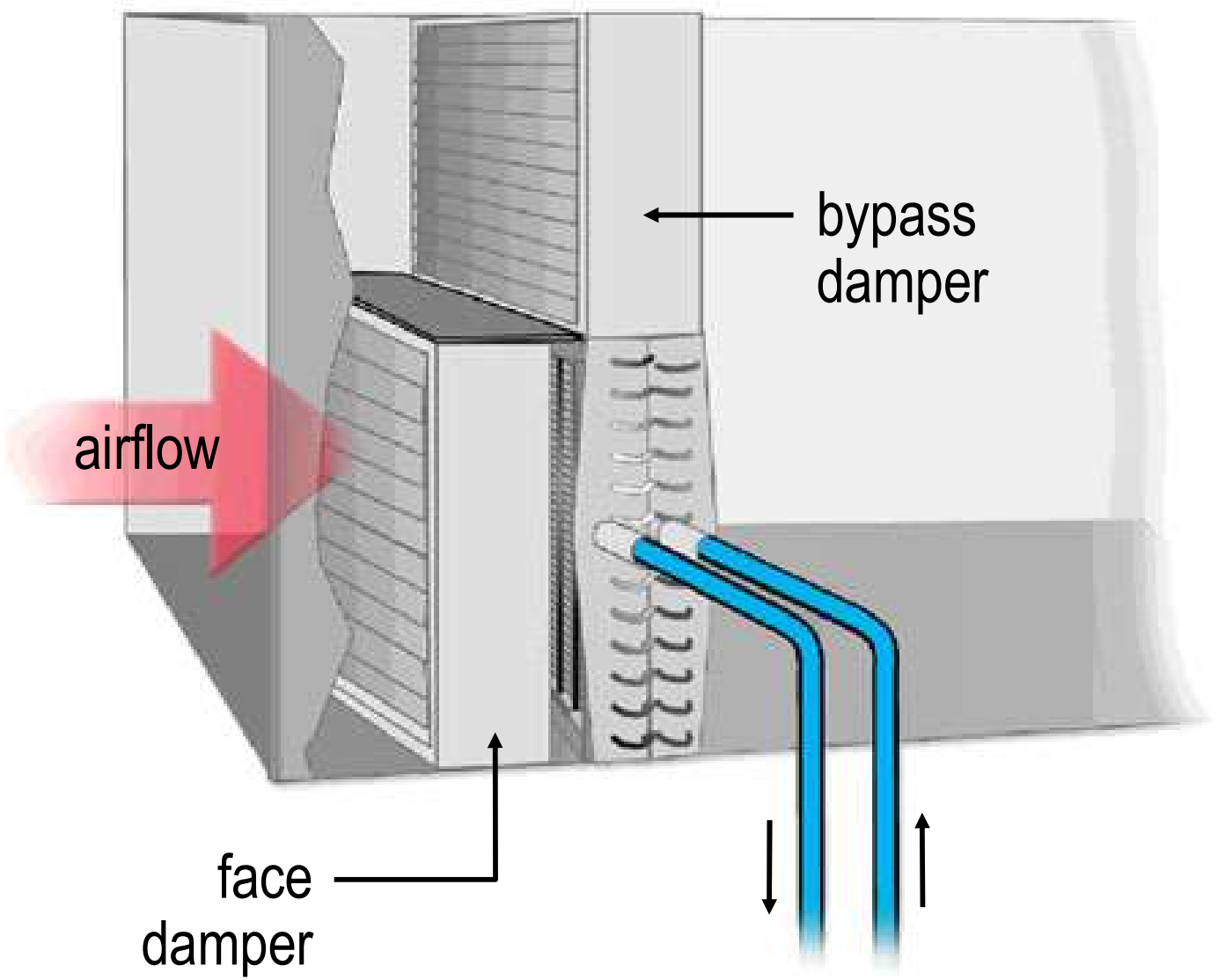
Three-Way Valve Control



Two-Way Valve Control



Face-and-Bypass Damper Control

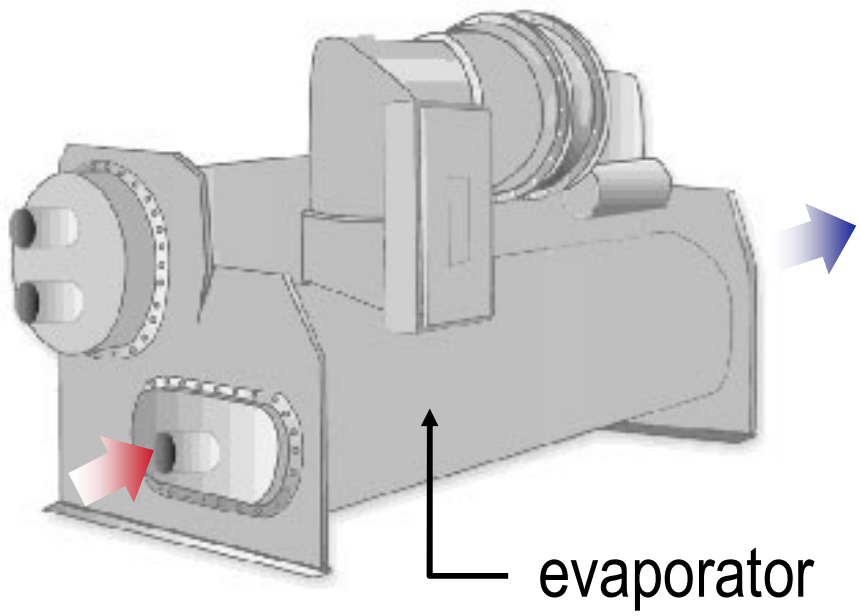


Load-Terminal Control Options

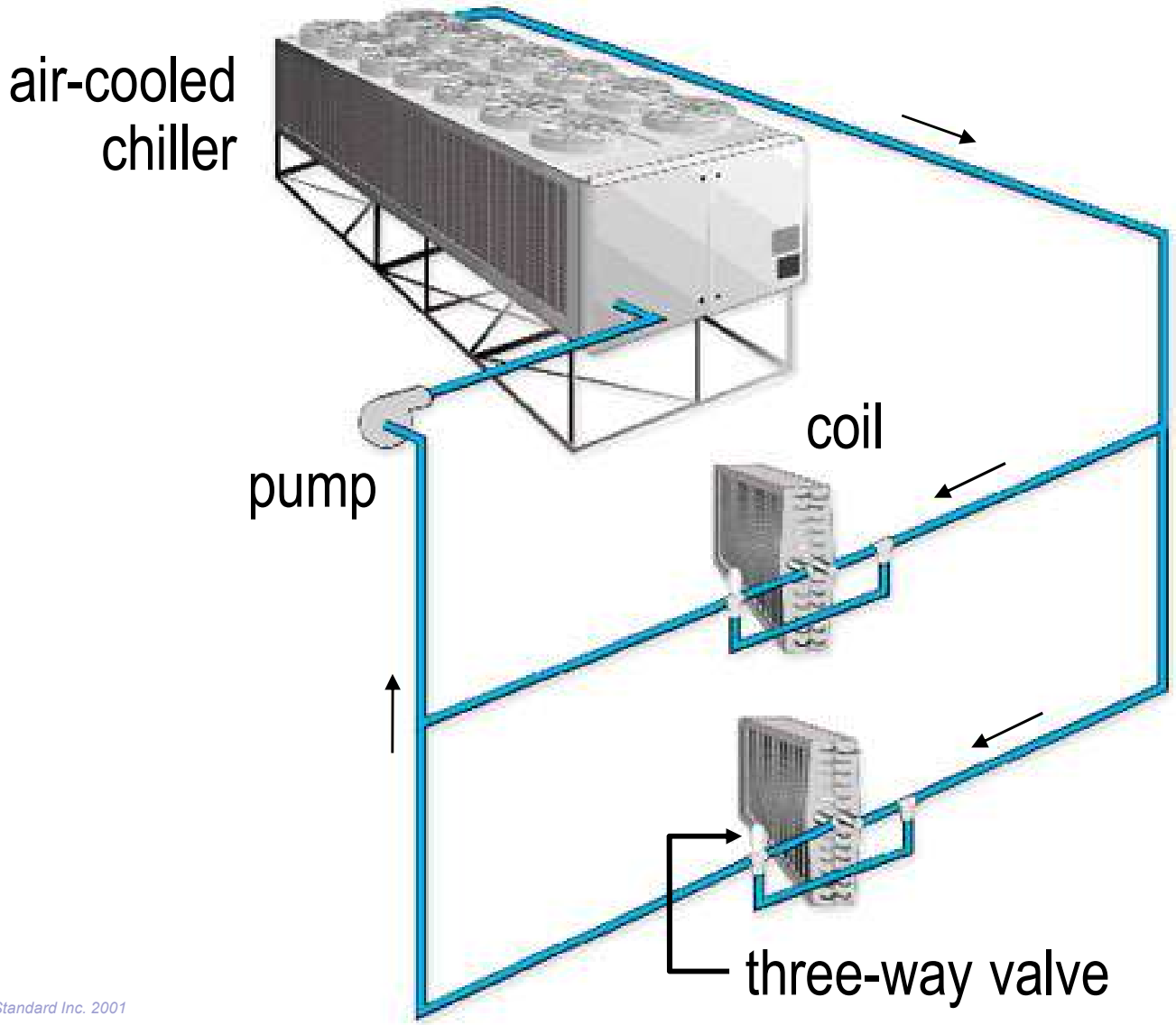
- **Three-way modulating valve**
  - Constant water flow
  - Variable return-water temperature
- **Two-way modulating valve**
  - Variable water flow (pump energy savings)
  - Constant return-water temperature
- **Face-and-bypass dampers**
  - Constant water flow
  - Variable return-water temperature
  - Enhanced dehumidification capability with “wild” coils

Chiller Evaporator Flow

- **Constant flow is most common**
- **Variable flow is possible**
  - Can reduce energy consumption
  - Use only with advanced chiller and system controls



Single-Chiller System

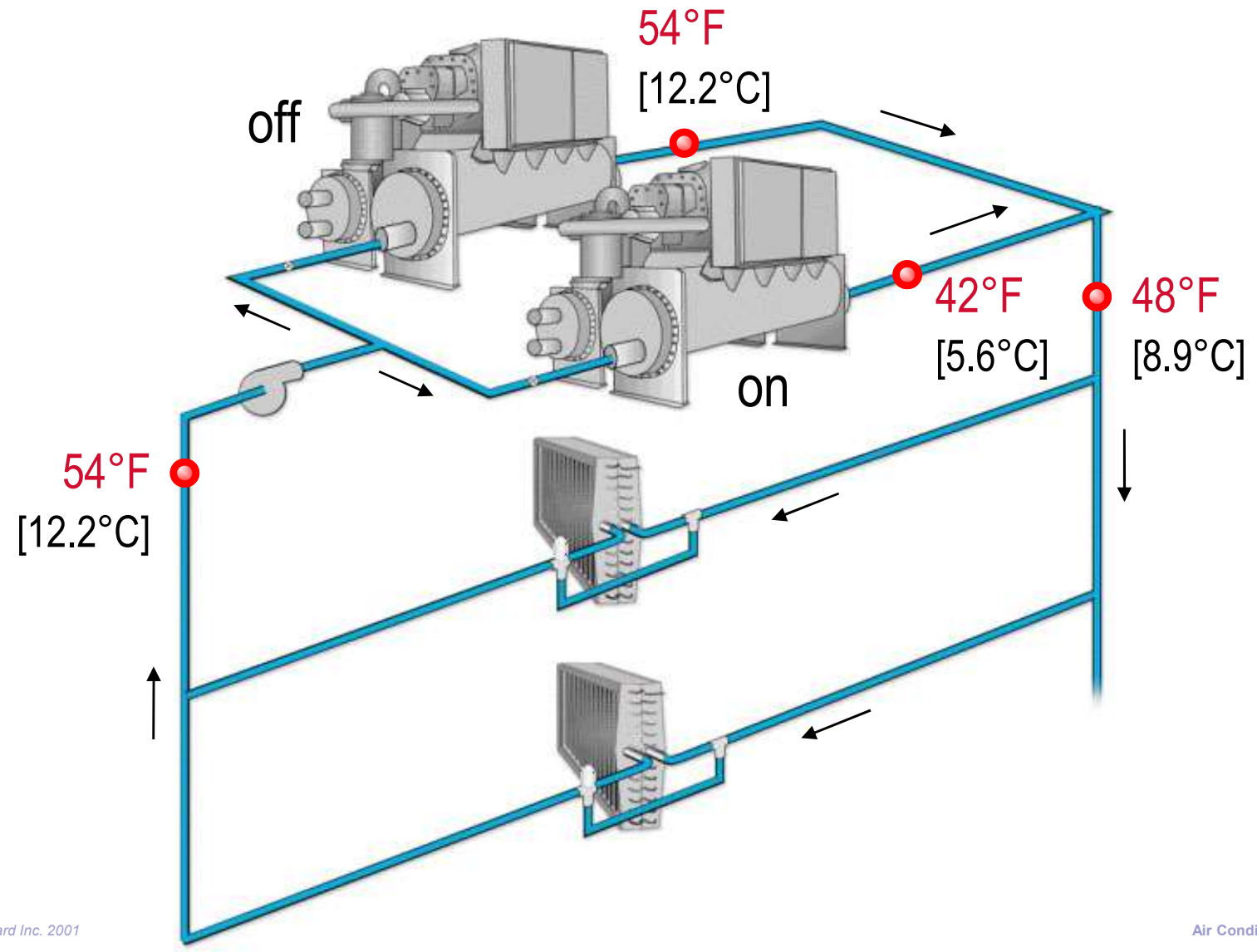


Multiple-Chiller Systems

- Redundancy
- Part-load efficiency

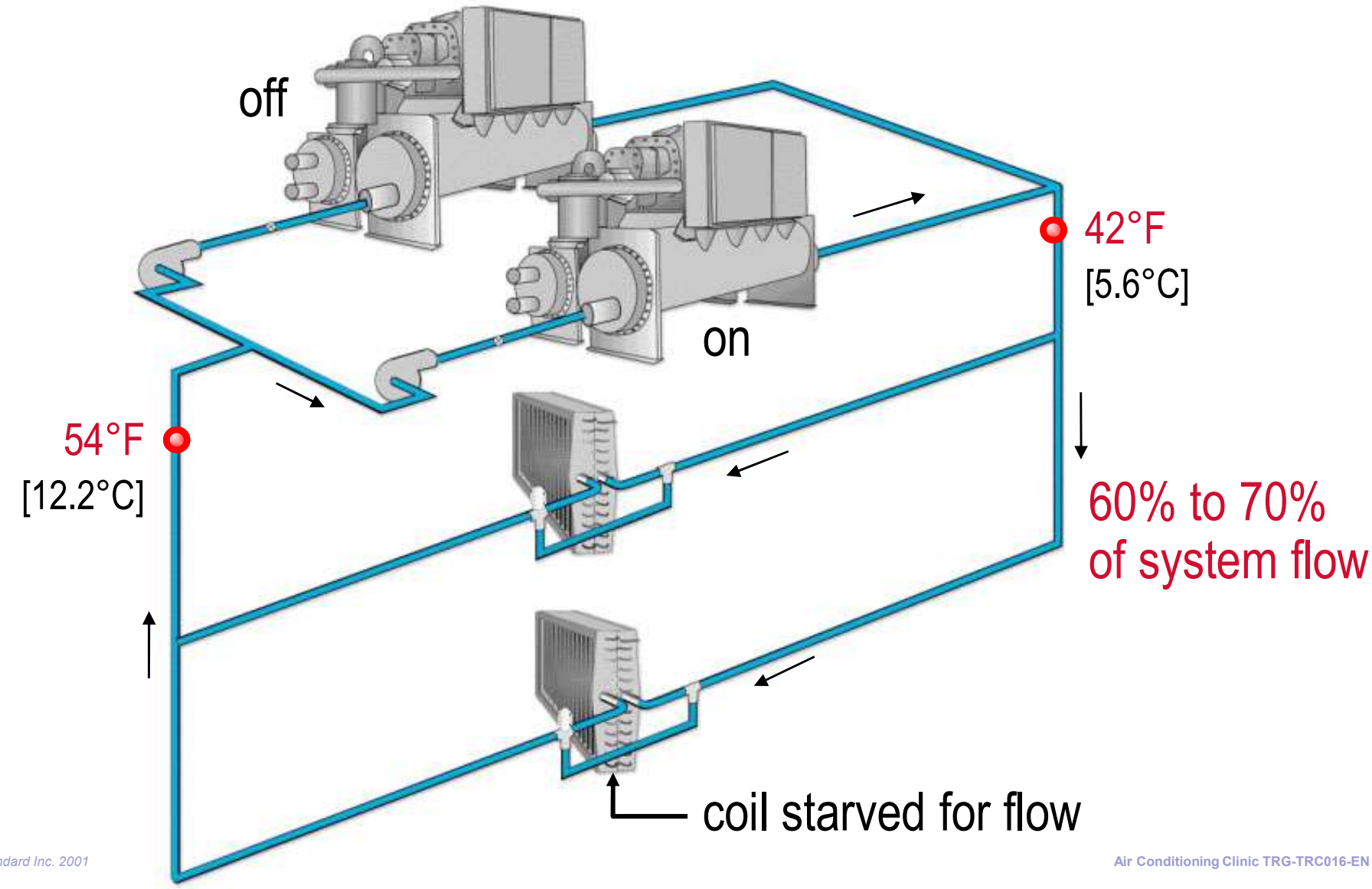
chillers piped in parallel

Single Pump



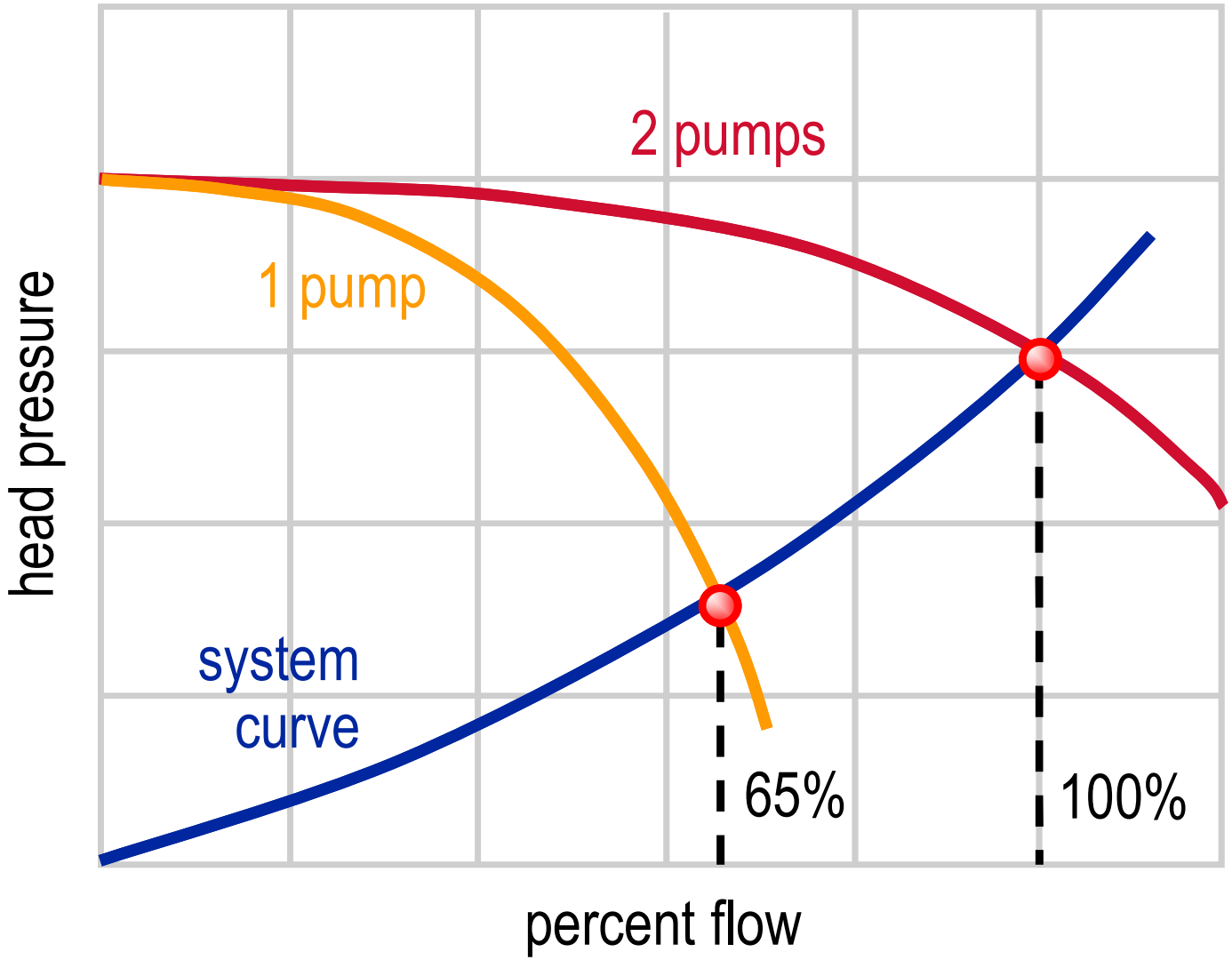
chillers piped in parallel

Dedicated Pumps

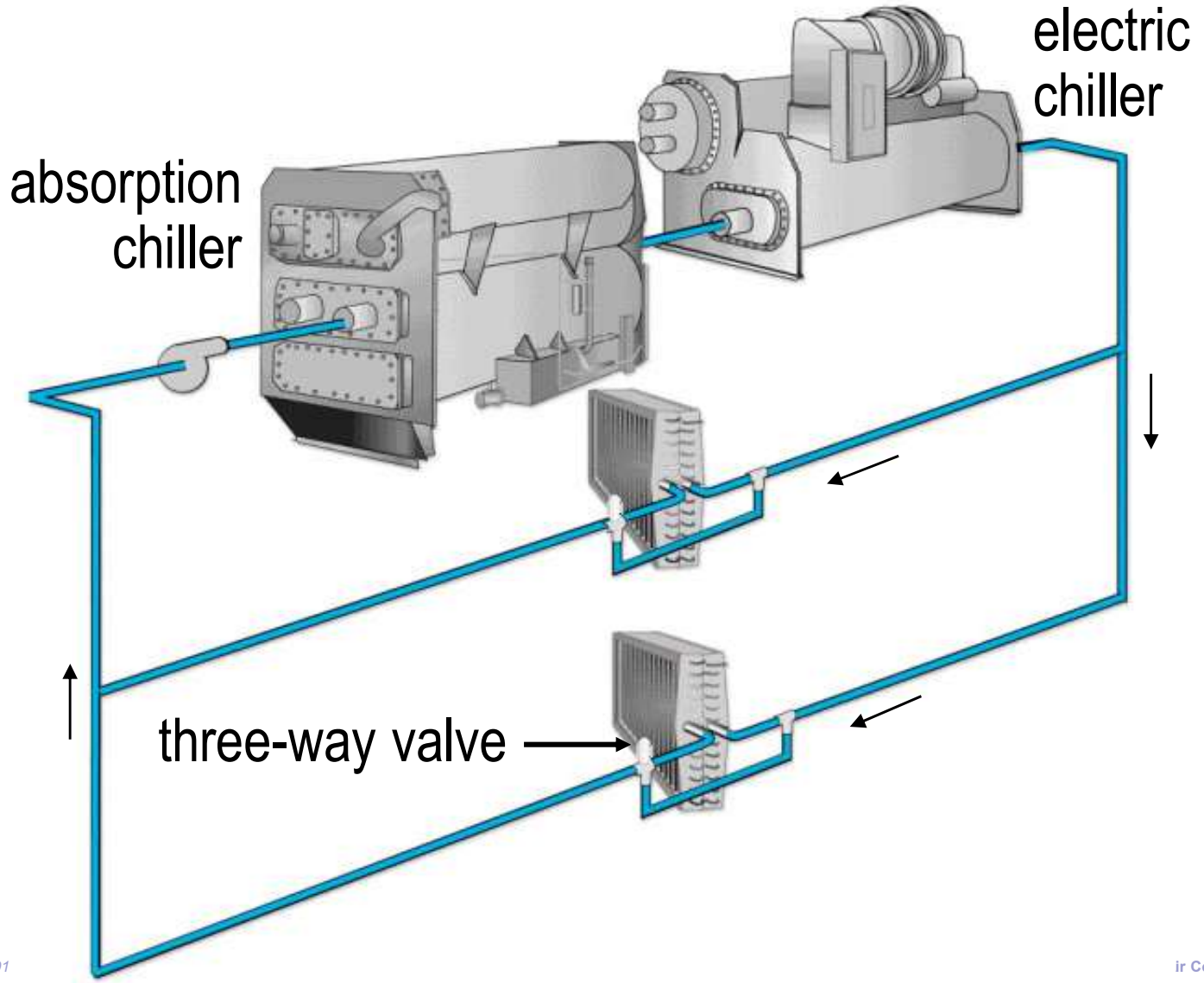


chillers piped in parallel

Dedicated Pumps

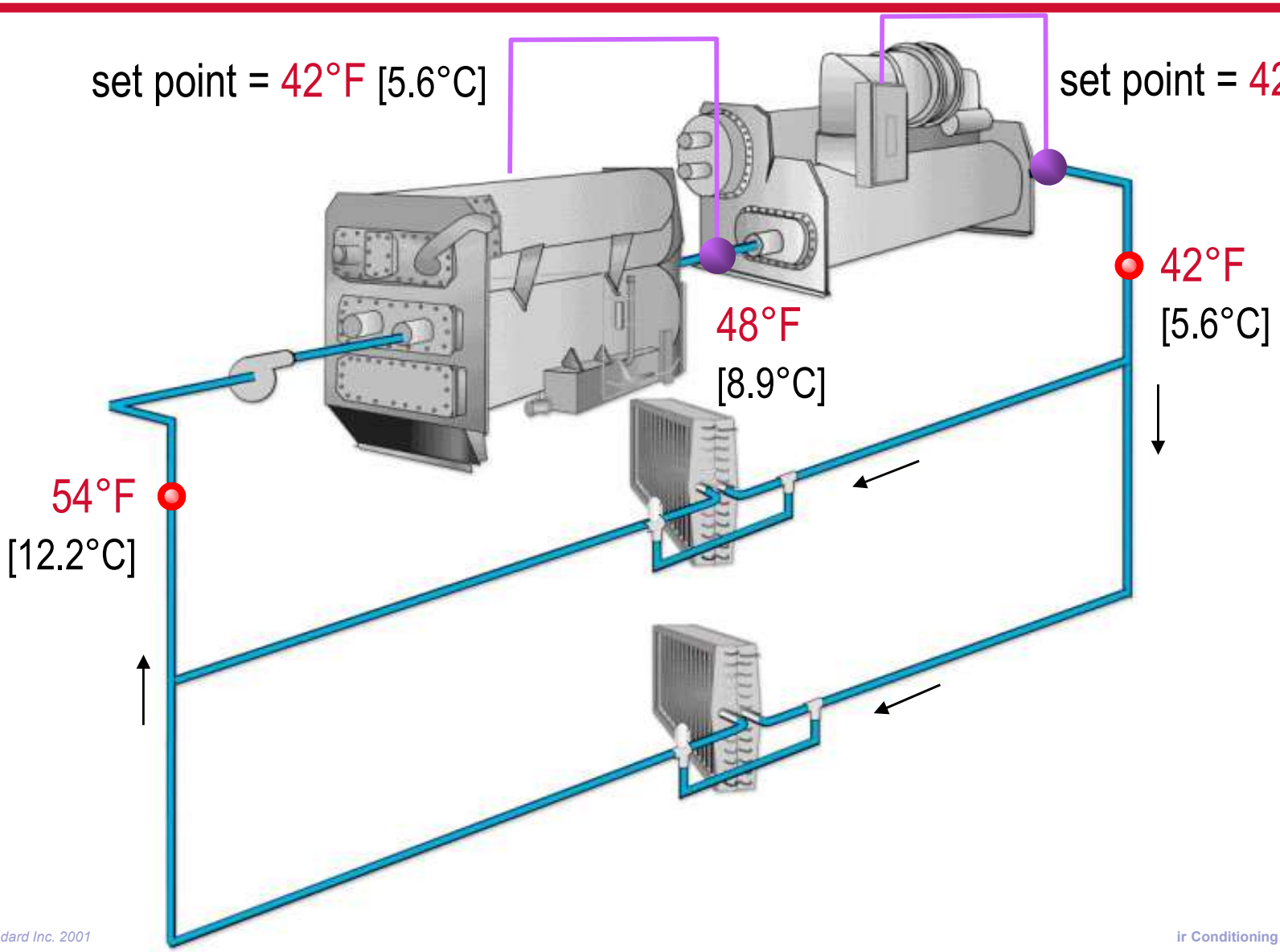


Chillers Piped in Series



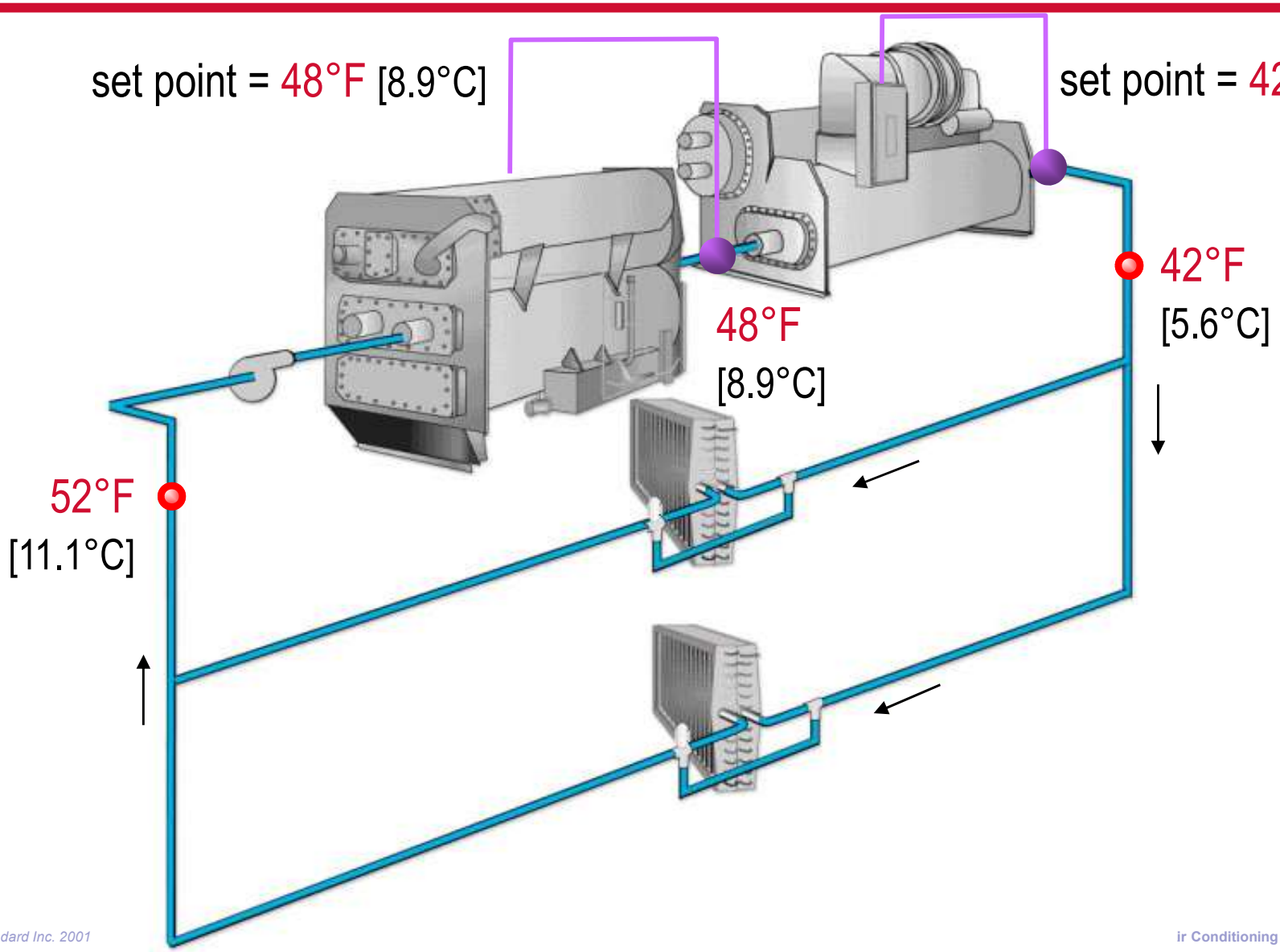
chillers piped in series

Equal Set Points

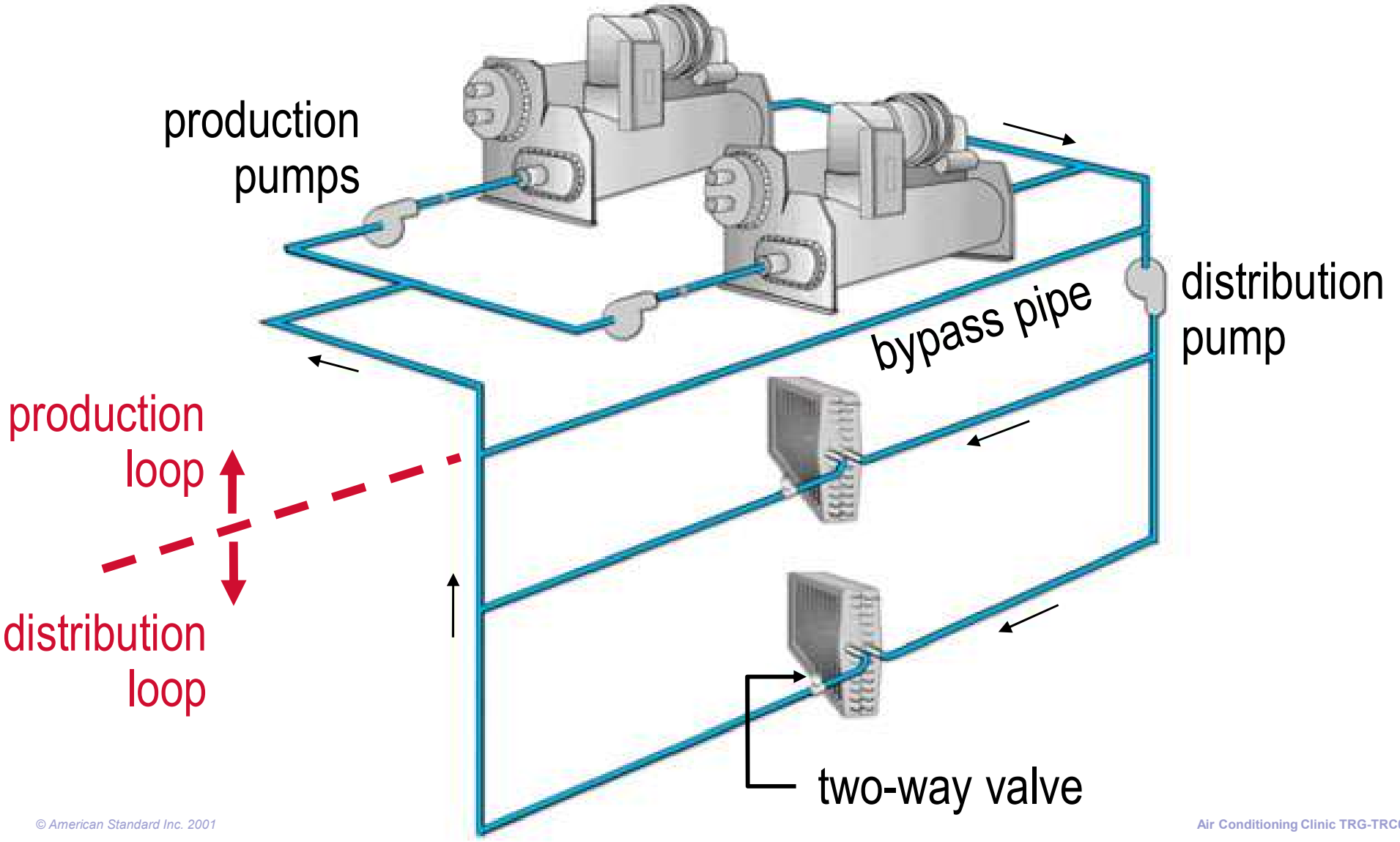


chillers piped in series

Staggered Set Points



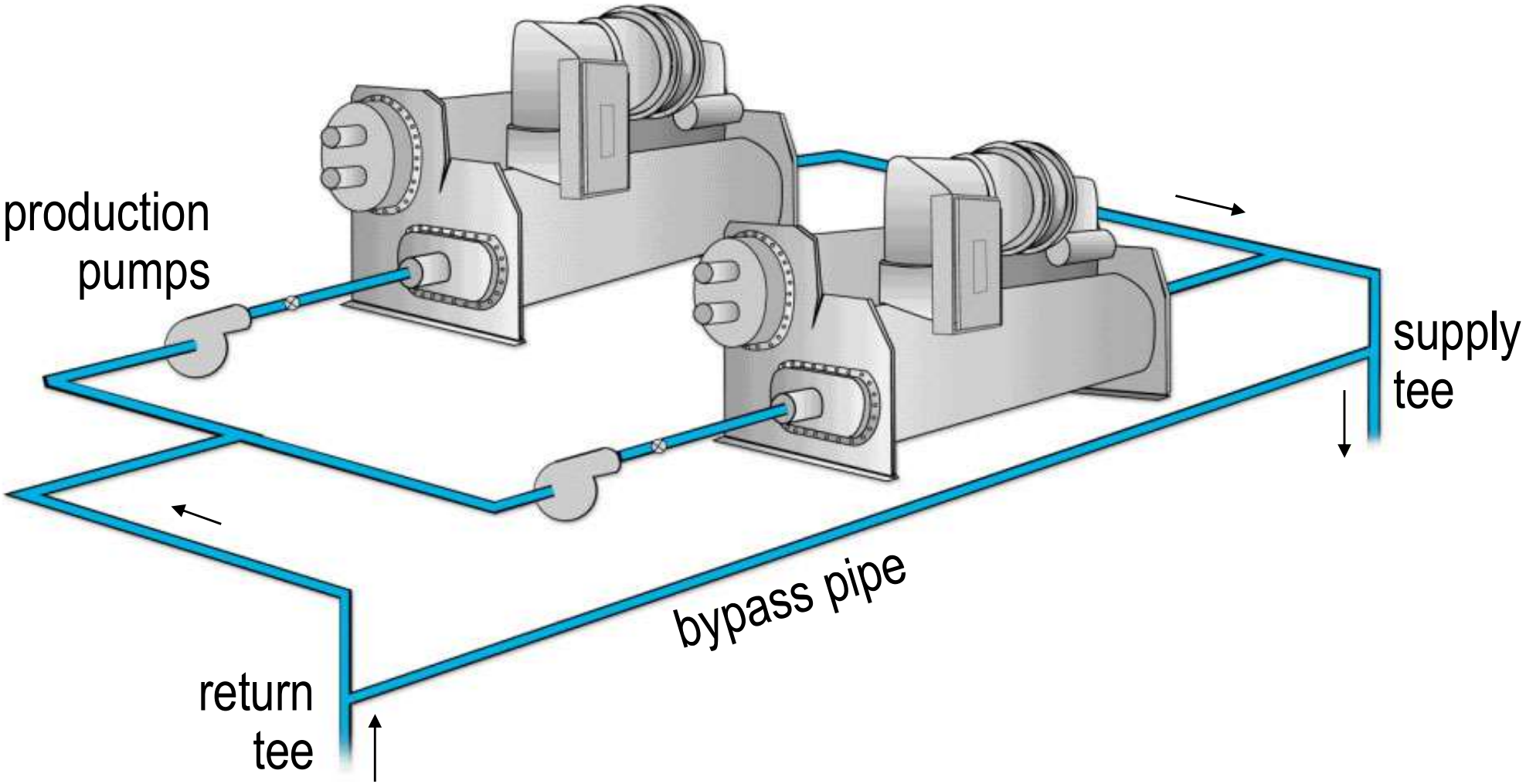
Primary-Secondary Configuration



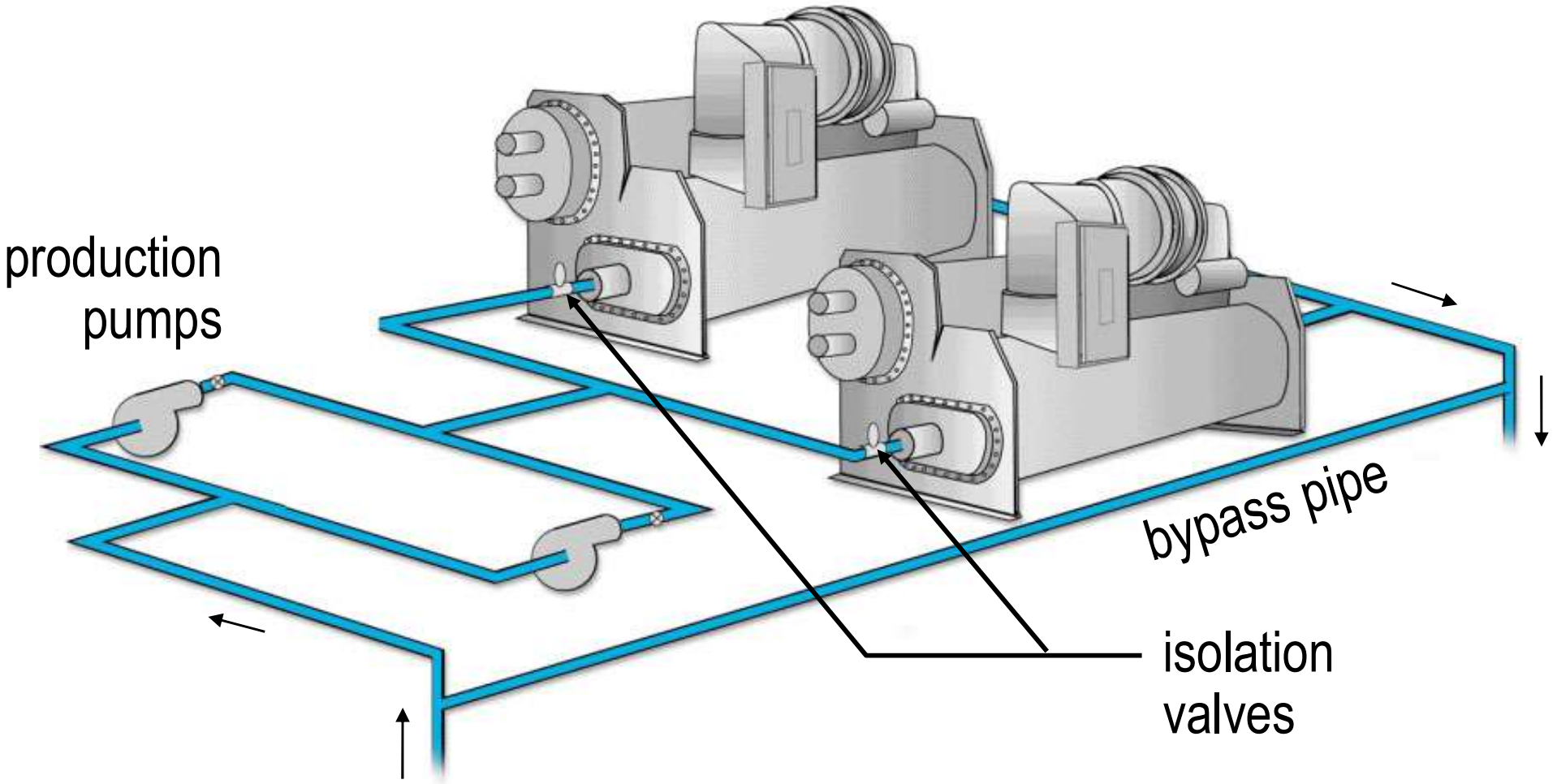
Primary-Secondary System Rules

- **The bypass pipe should be free of restrictions**
  - Sized for minimal pressure drop
  - Avoid random mixing of supply- and return-water streams
  - No check valve

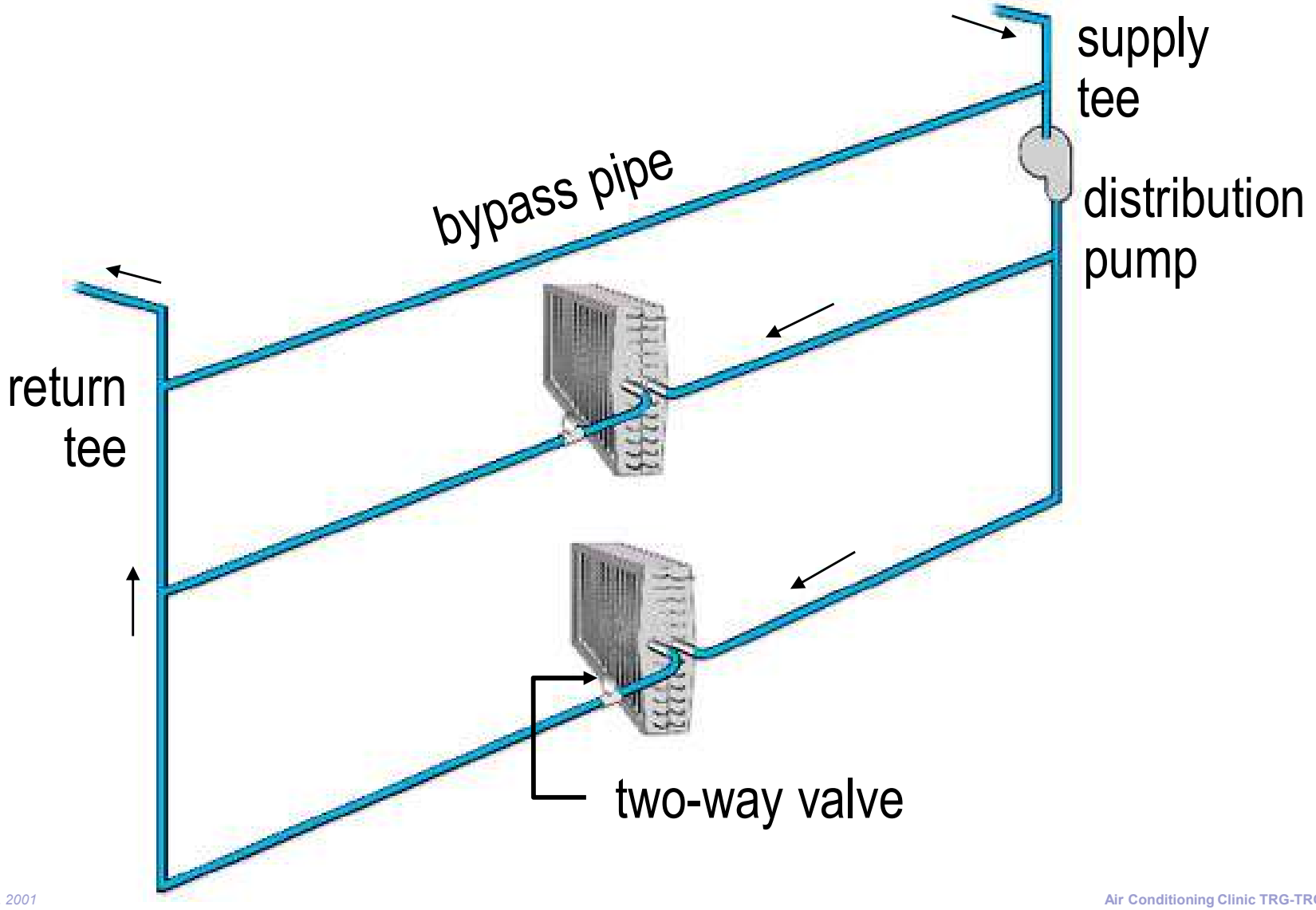
Production Loop



Manifolded Production Pumps



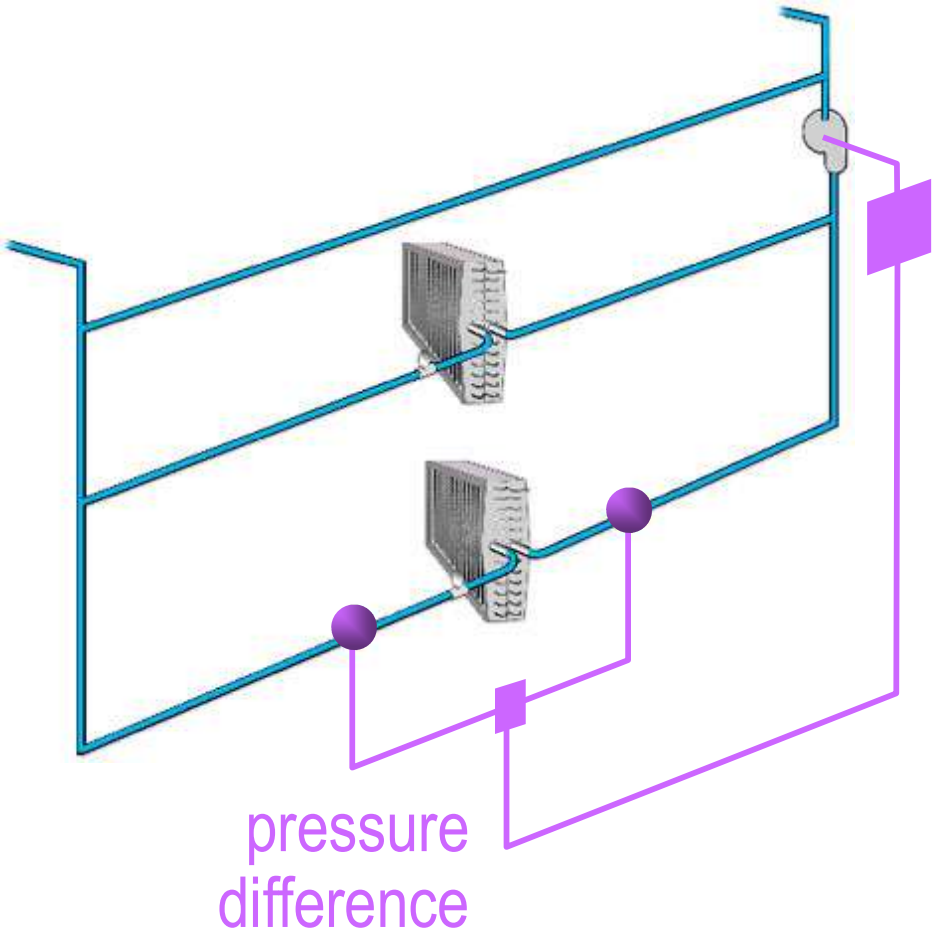
Distribution Loop



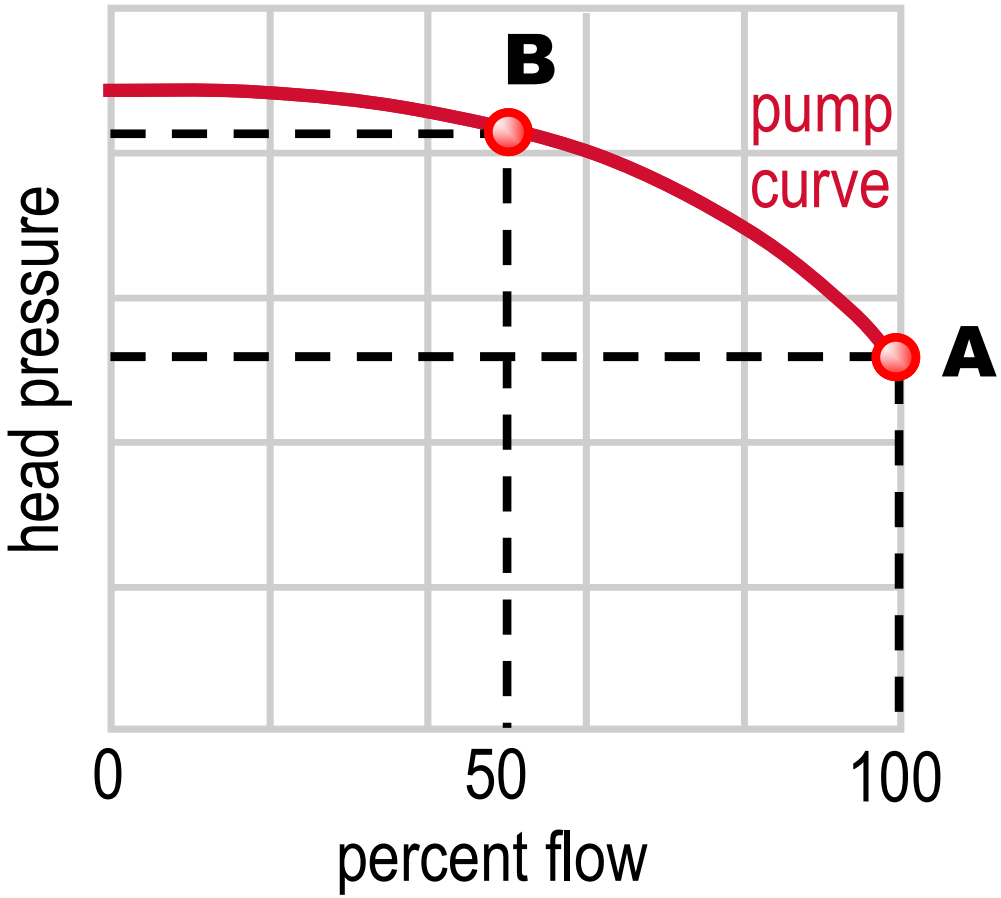
Primary-Secondary System Rules

- The bypass pipe should be free of restrictions
- **Load terminals should use two-way modulating control valves**

Varying Distribution Flow

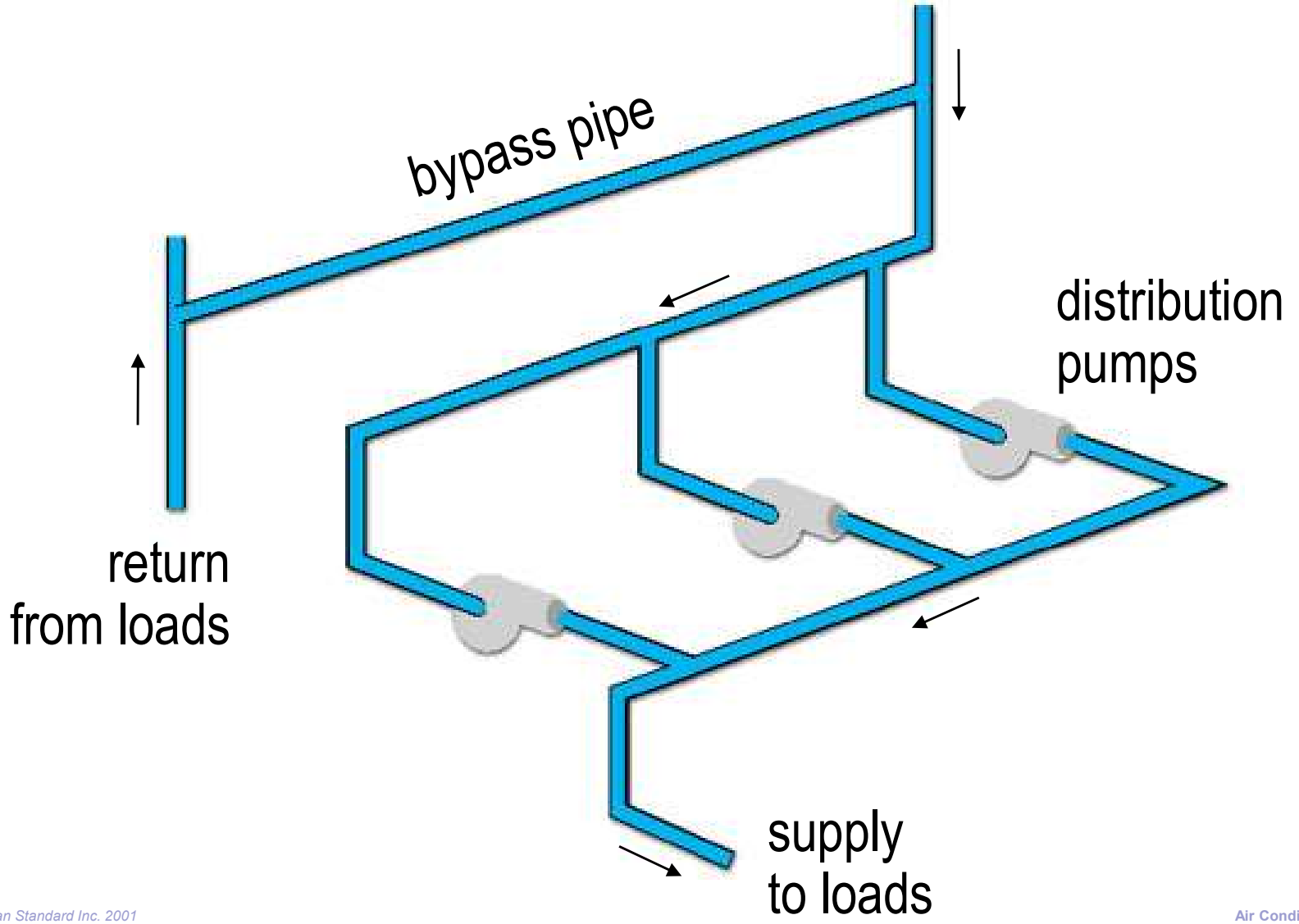


variable-speed control

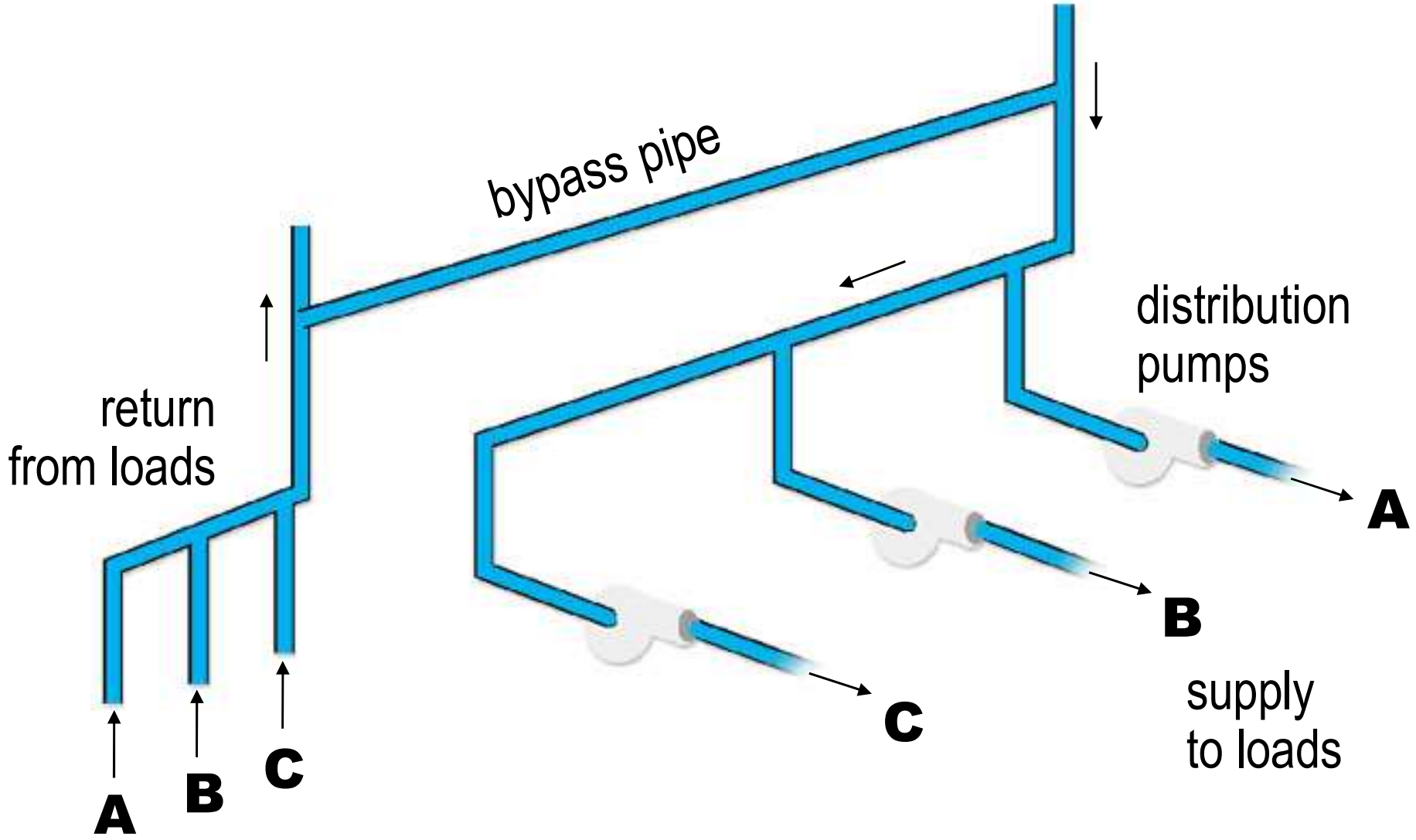


riding the pump curve

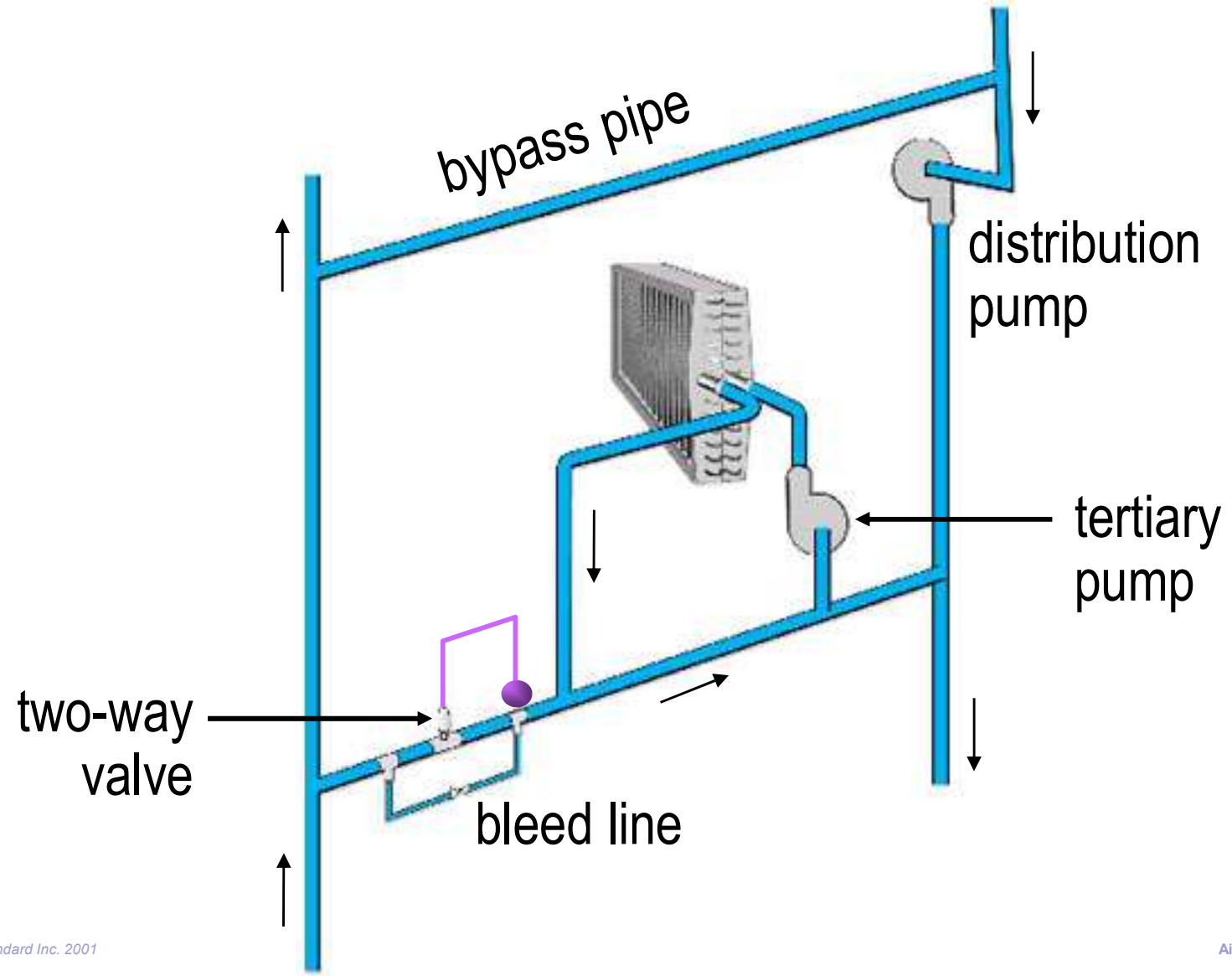
Multiple Distribution Pumps



Multiple Distribution Pumps

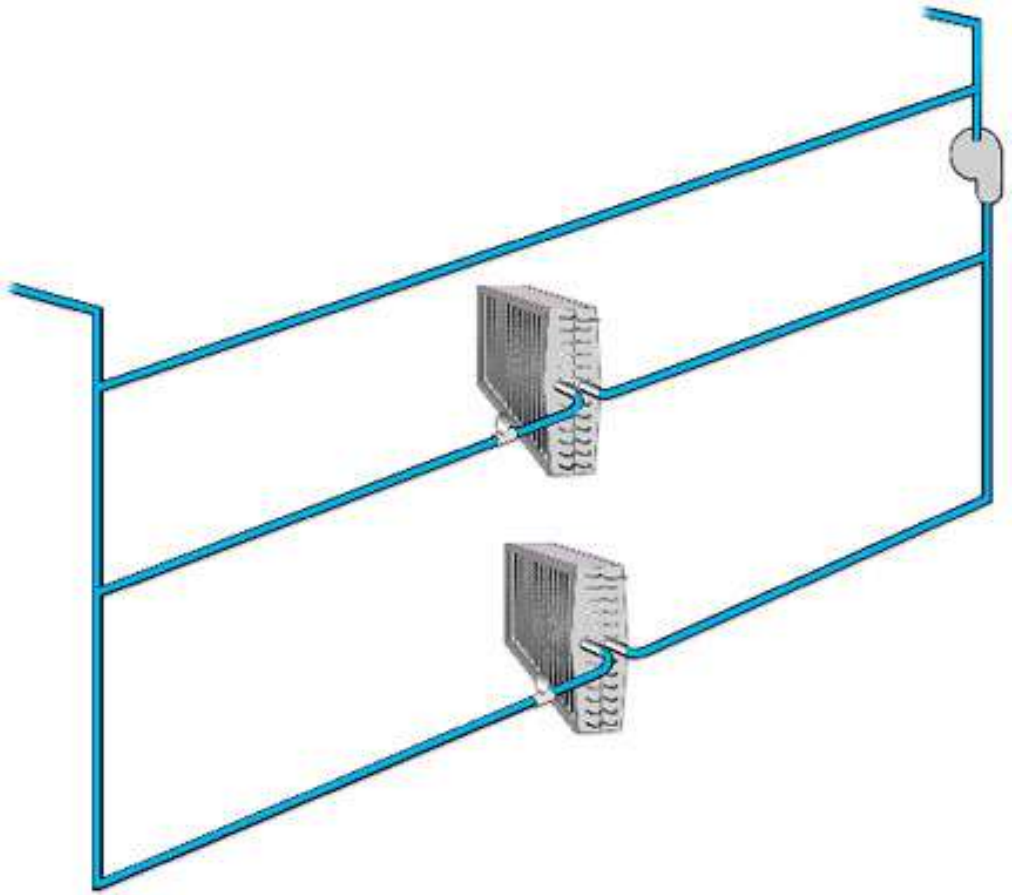


Tertiary Pumping



Distribution Loop Characteristics

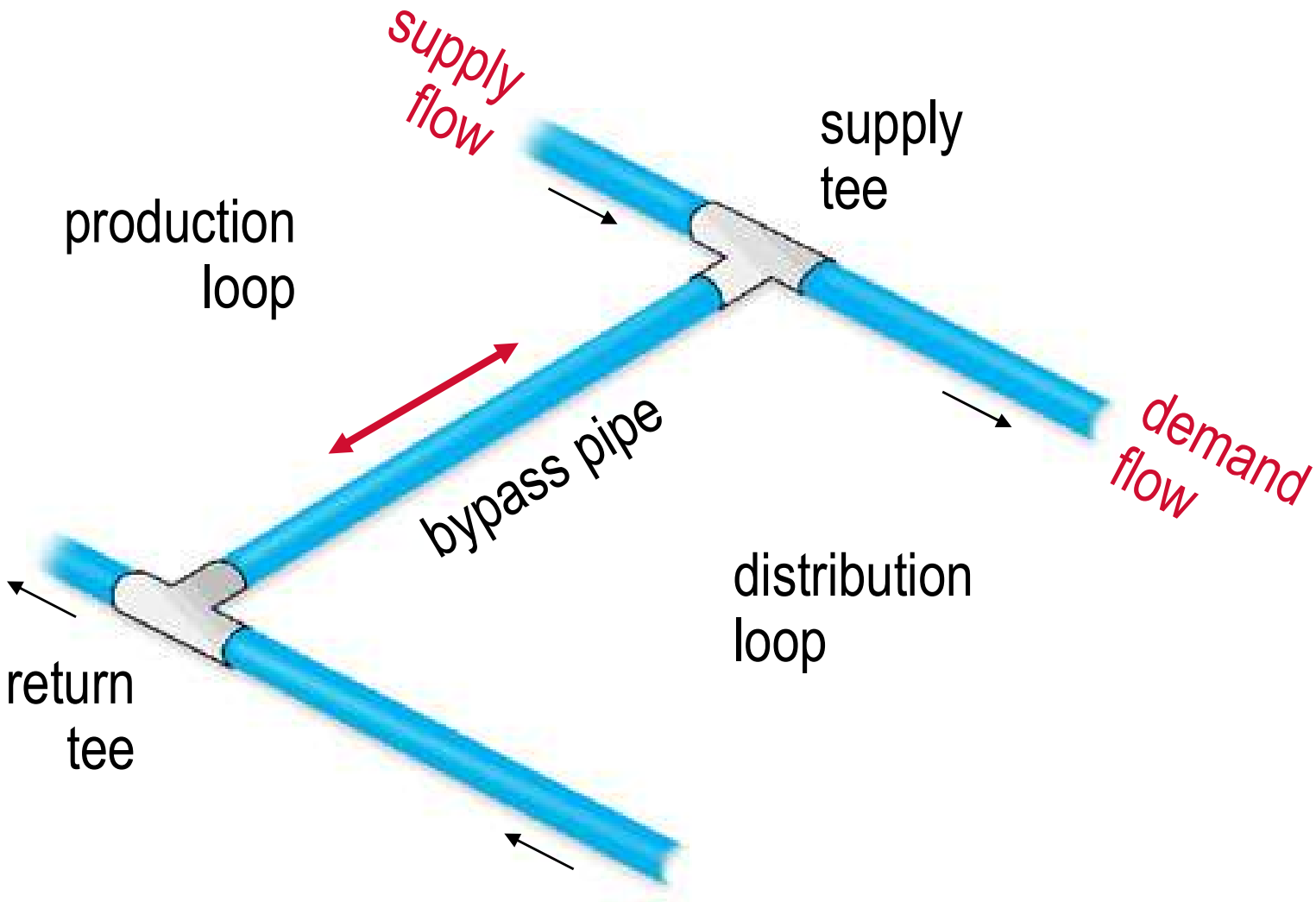
- Reduced pump energy use
- Distribution loop sized for system diversity
- Higher return-water temperatures



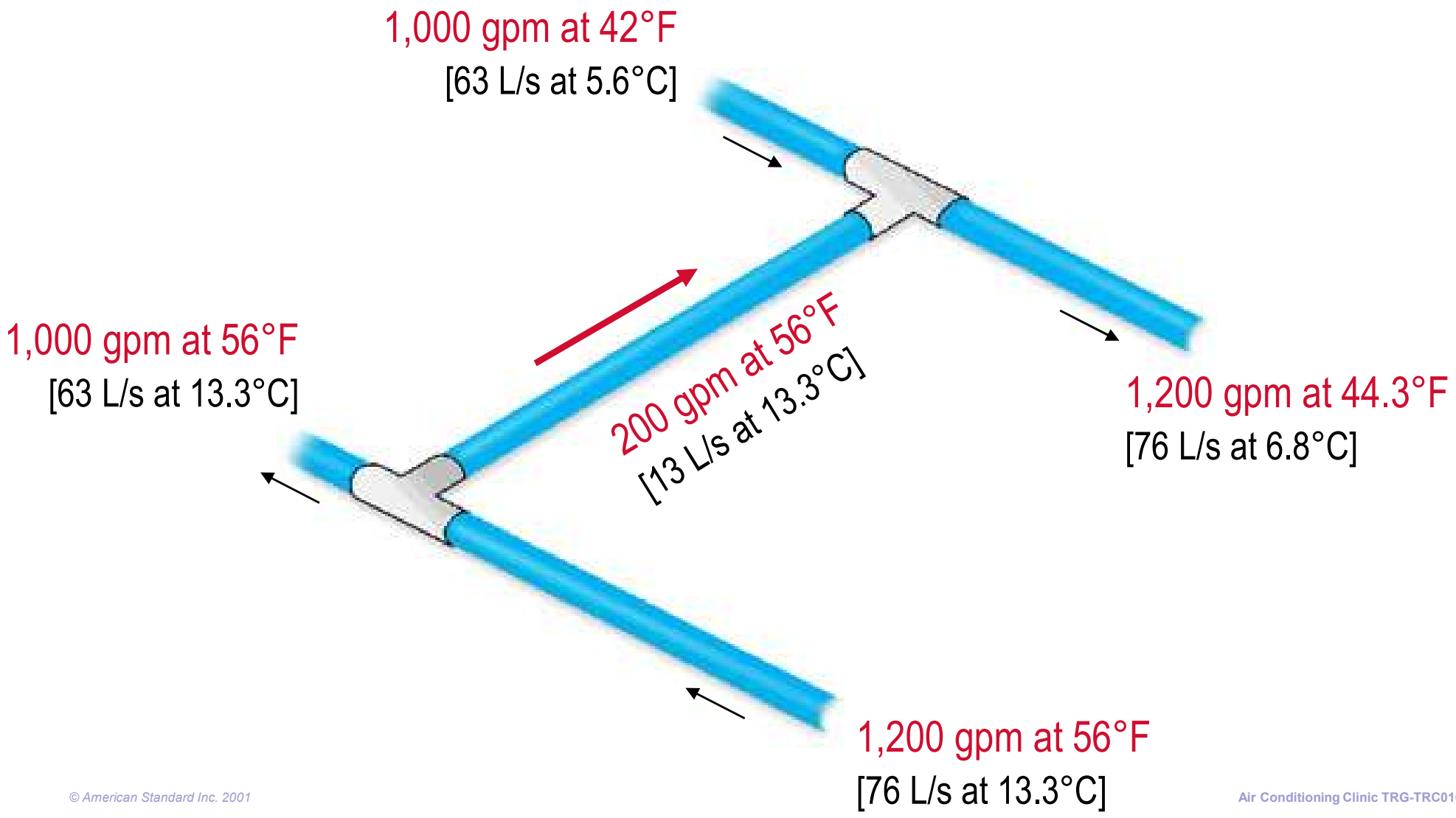
Primary-Secondary System Rules

- The bypass pipe should be free of restrictions
- Load terminals should use two-way modulating control valves
- **All chillers should be selected for the same leaving chilled-water temperature and ΔT**

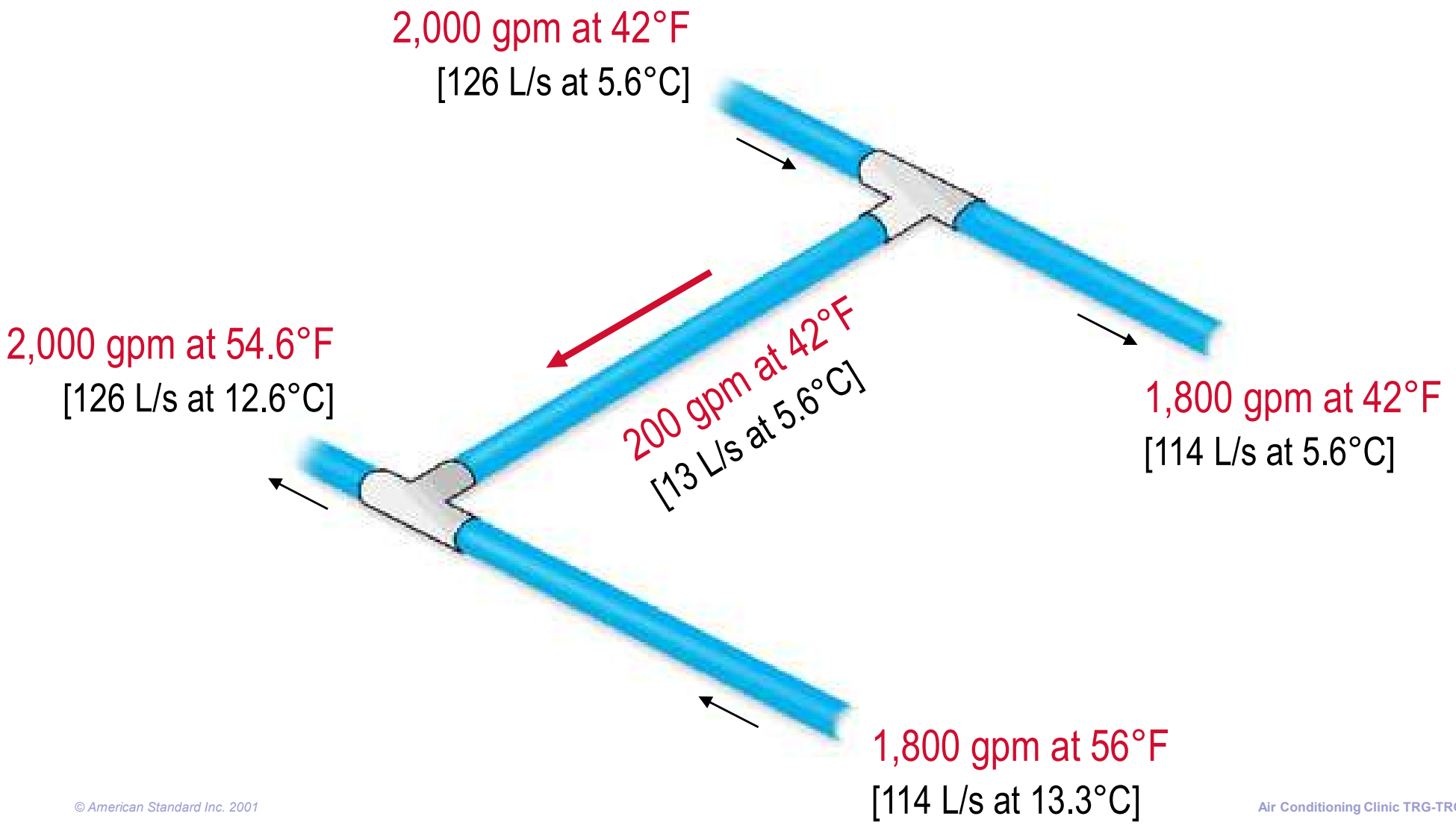
System Operation



Deficit Flow



Excess Flow



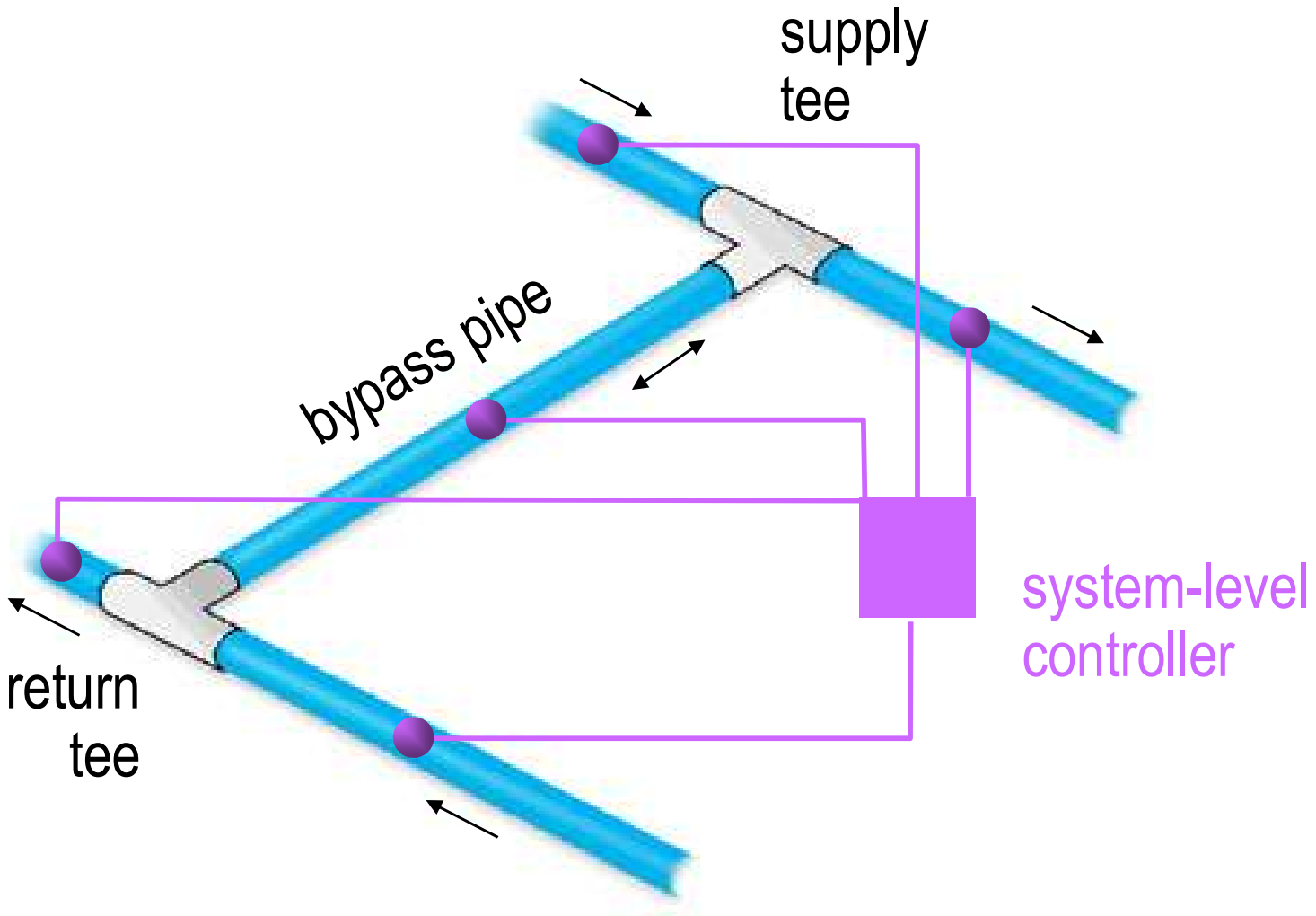
Control of Primary-Secondary System

condition	response
deficit flow for specified period of time	start another chiller and pump
excess flow greater than 110% to 115% of next pump to turn off	turn off next chiller and pump
neither	do nothing

Types of Fluid Flow Meters

- **Pressure-based**
  - Pitot tube
  - Venturi
  - Orifice plate
  - Differential pressure
- **Turbine and impeller**
- **Vortex**
- **Magnetic**
- **Ultrasonic**

Temperature-Based Calculations

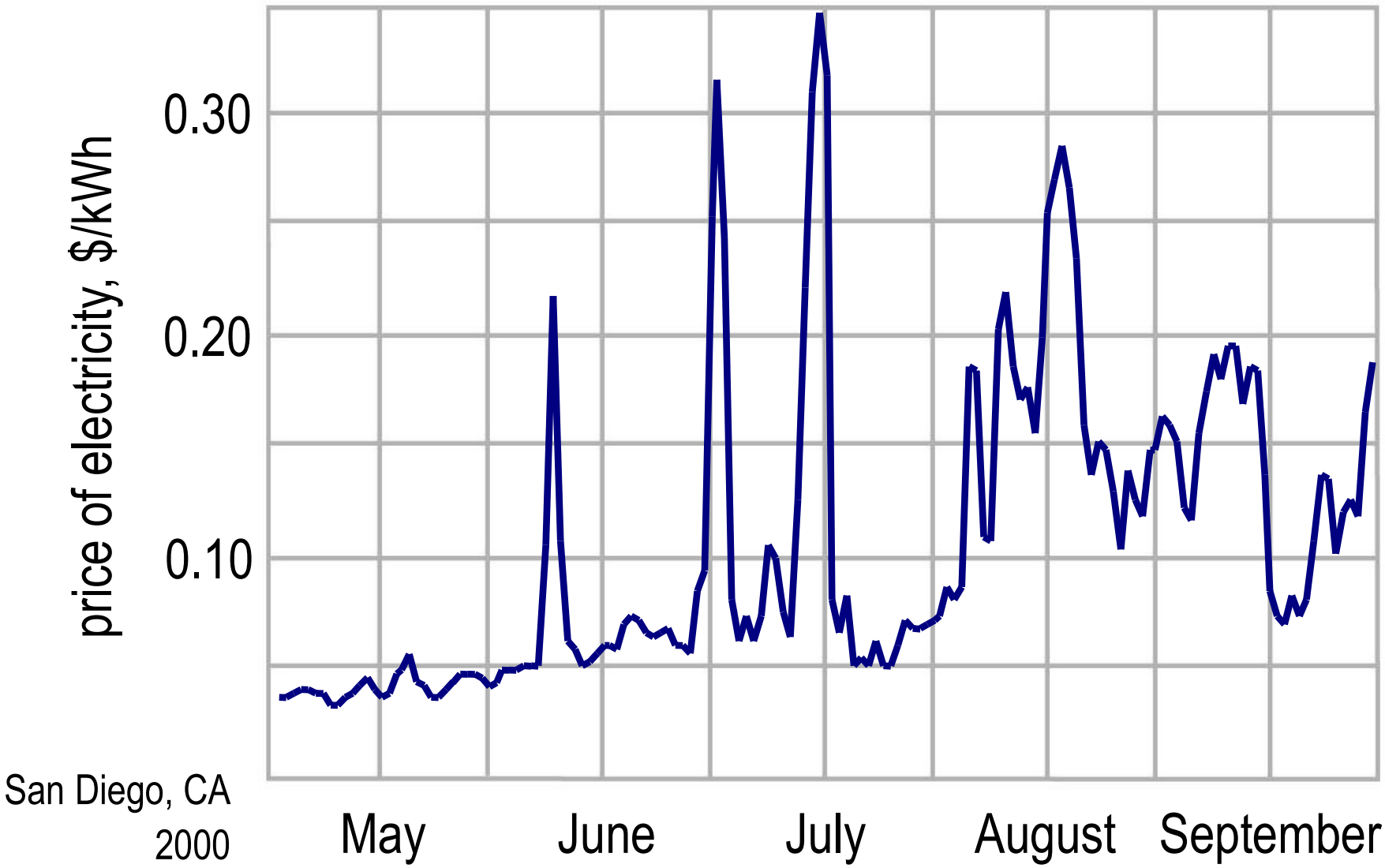


Chilled-Water Systems

period three

System Variations

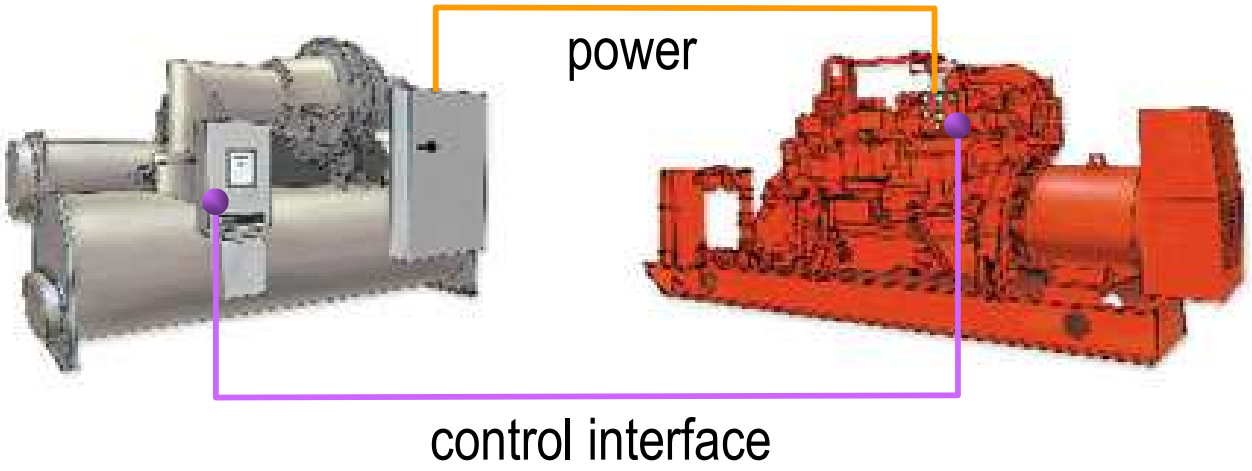
Electric Utility Deregulation



Fuel Choice Options

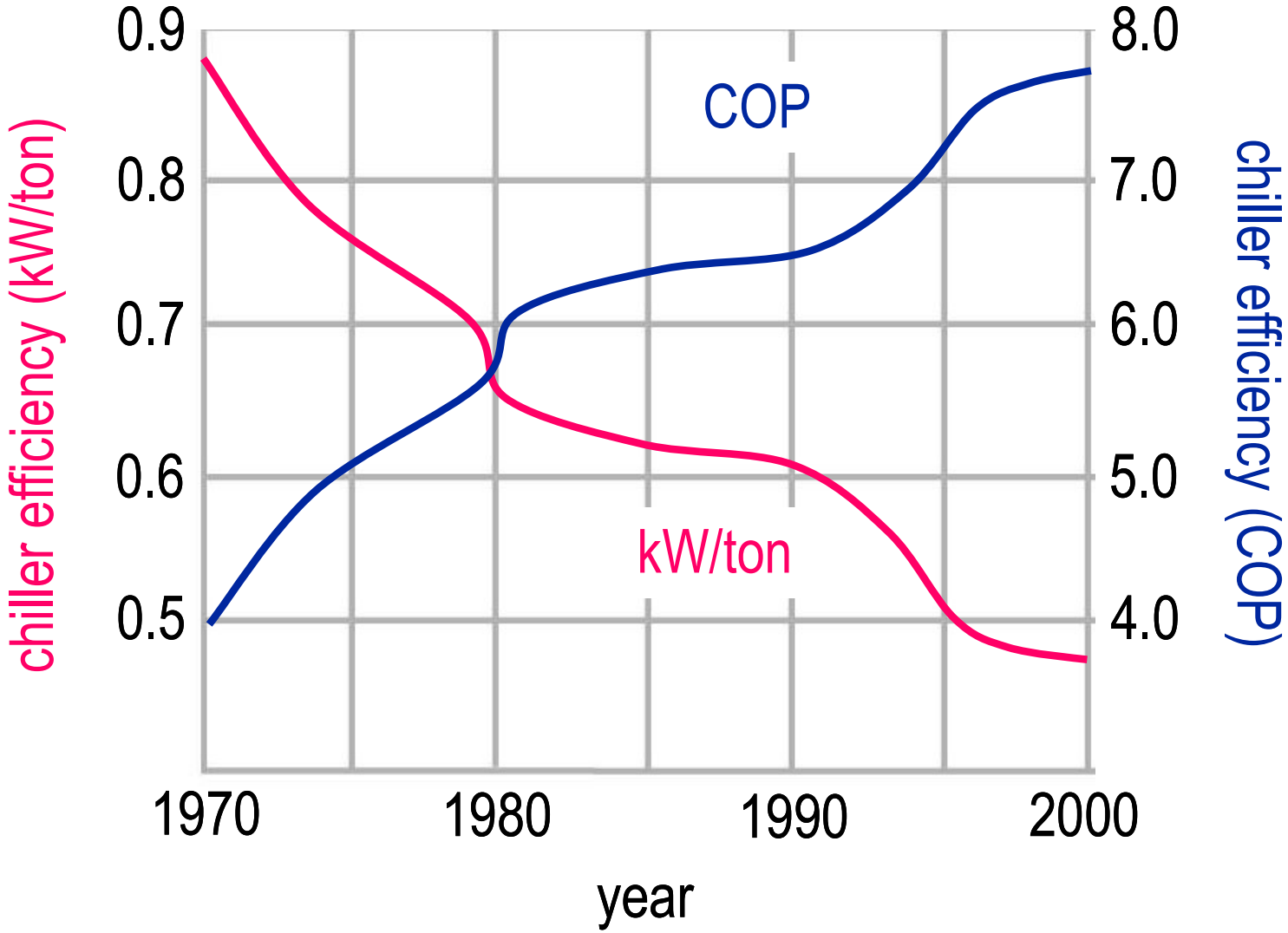
absorption

thermal storage



indirectly-coupled, gas-engine chillers

Chiller Efficiency Improvements

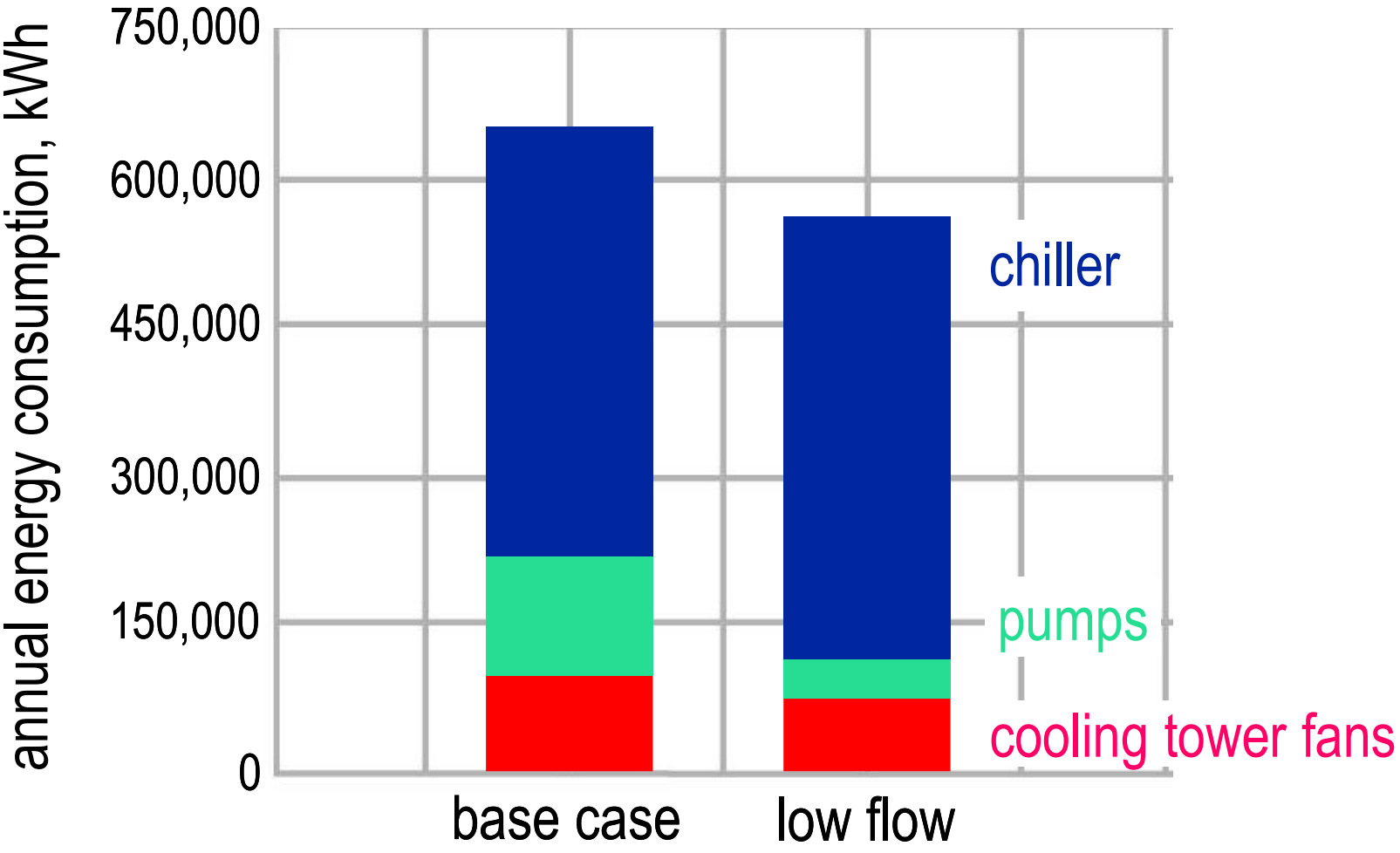


Greater Focus on System Efficiency

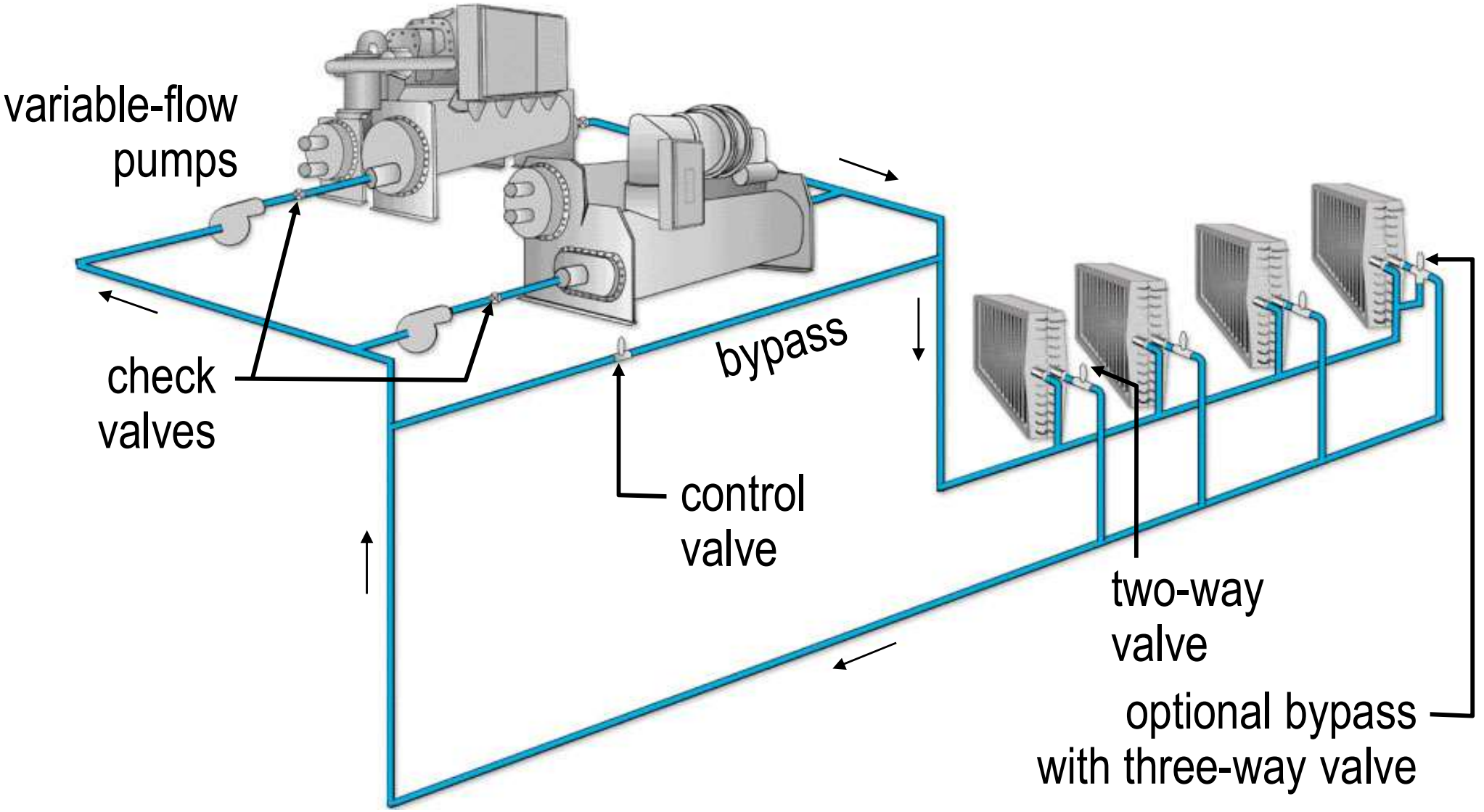
Trend Toward Lower Flow Rates

electric-driven chiller	yesterday	today
evaporator flow rate	2.4 gpm/ton [0.043 L/s/kW]	1.5 gpm/ton [0.027 L/s/kW]
leaving chilled-water temperature	44°F [6.7°C]	41°F [5°C]
condenser flow rate	3.0 gpm/ton [0.054 L/s/kW]	2.0 gpm/ton [0.036 L/s/kW]
entering condenser-water temperature	85°F [29.4°C]	85°F [29.4°C]

Low-Flow Systems



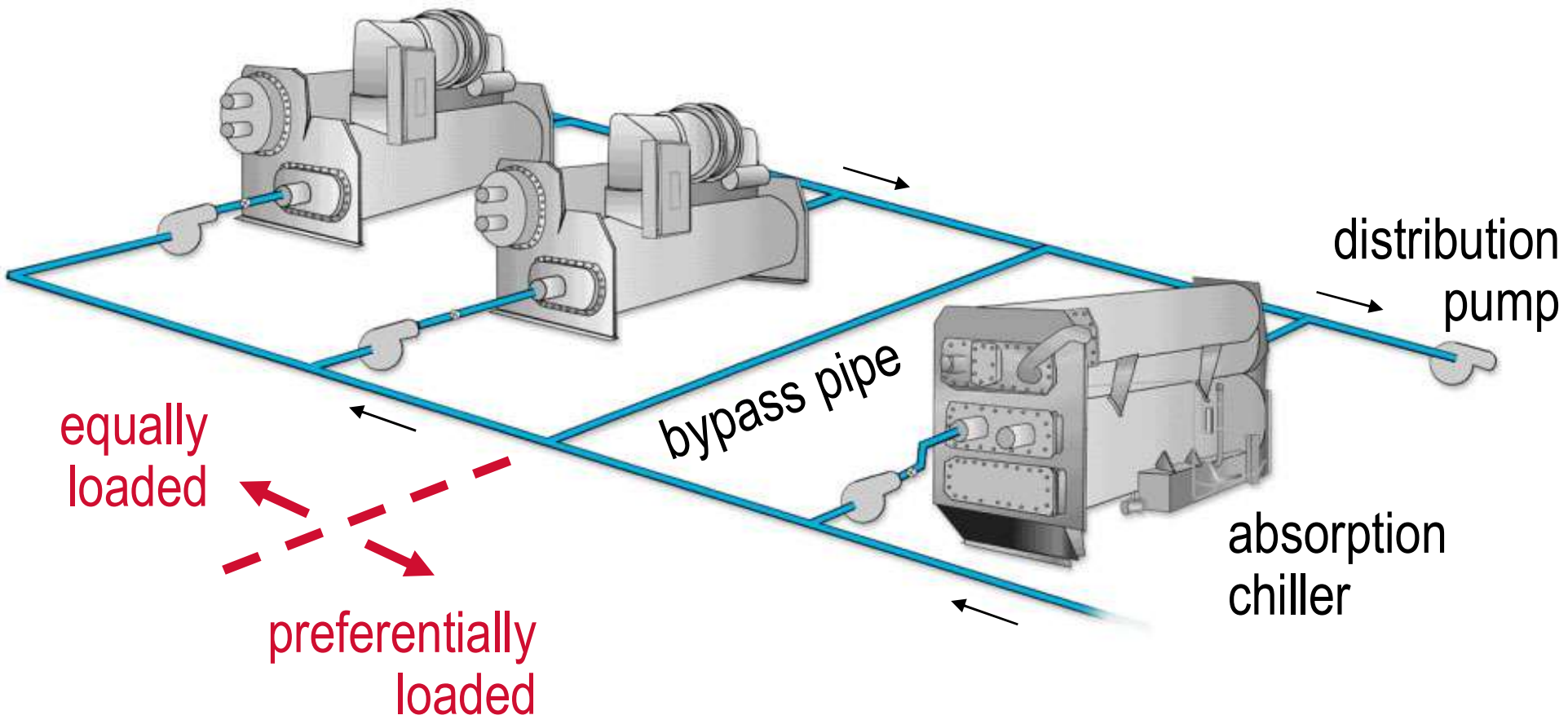
Variable-Primary-Flow Systems



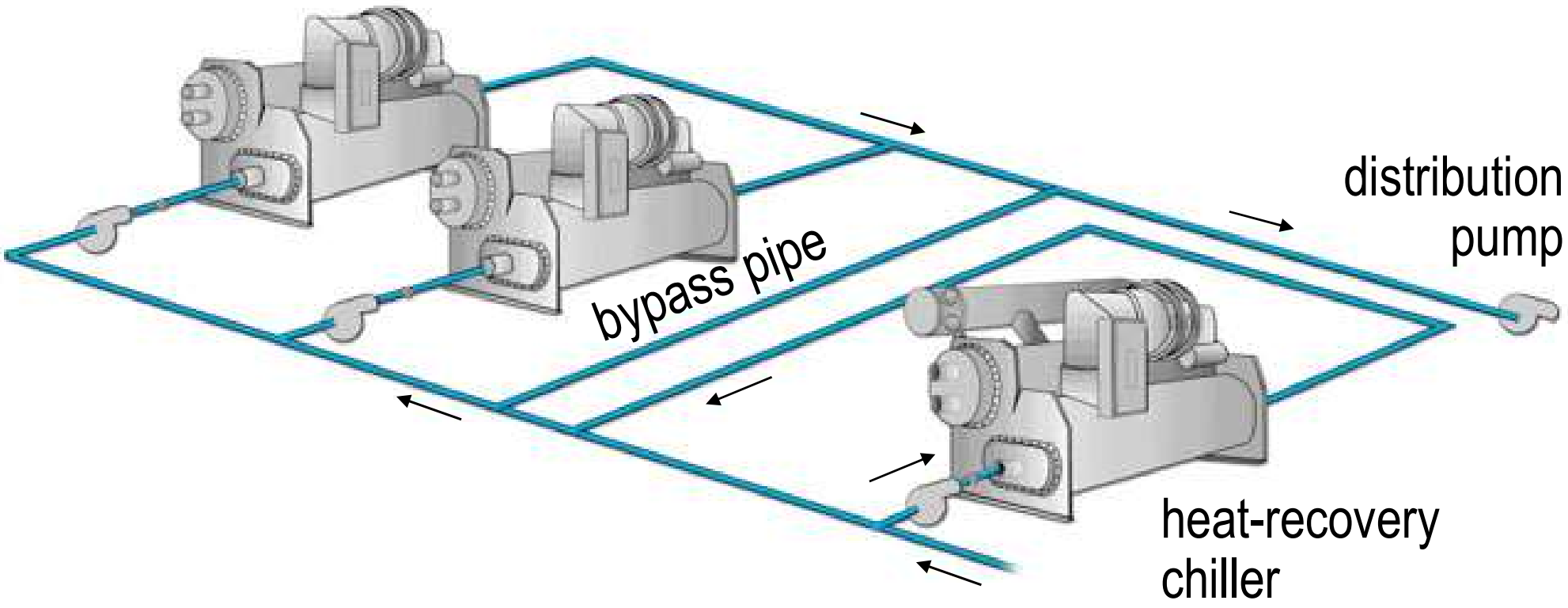
Critical VPF System Requirements

- Chillers must handle variable evaporator flow
- System must include a bypass
- System-level controls must limit the rate-of-flow change
- Adequate time to design and commission controls
- Operator must understand the system

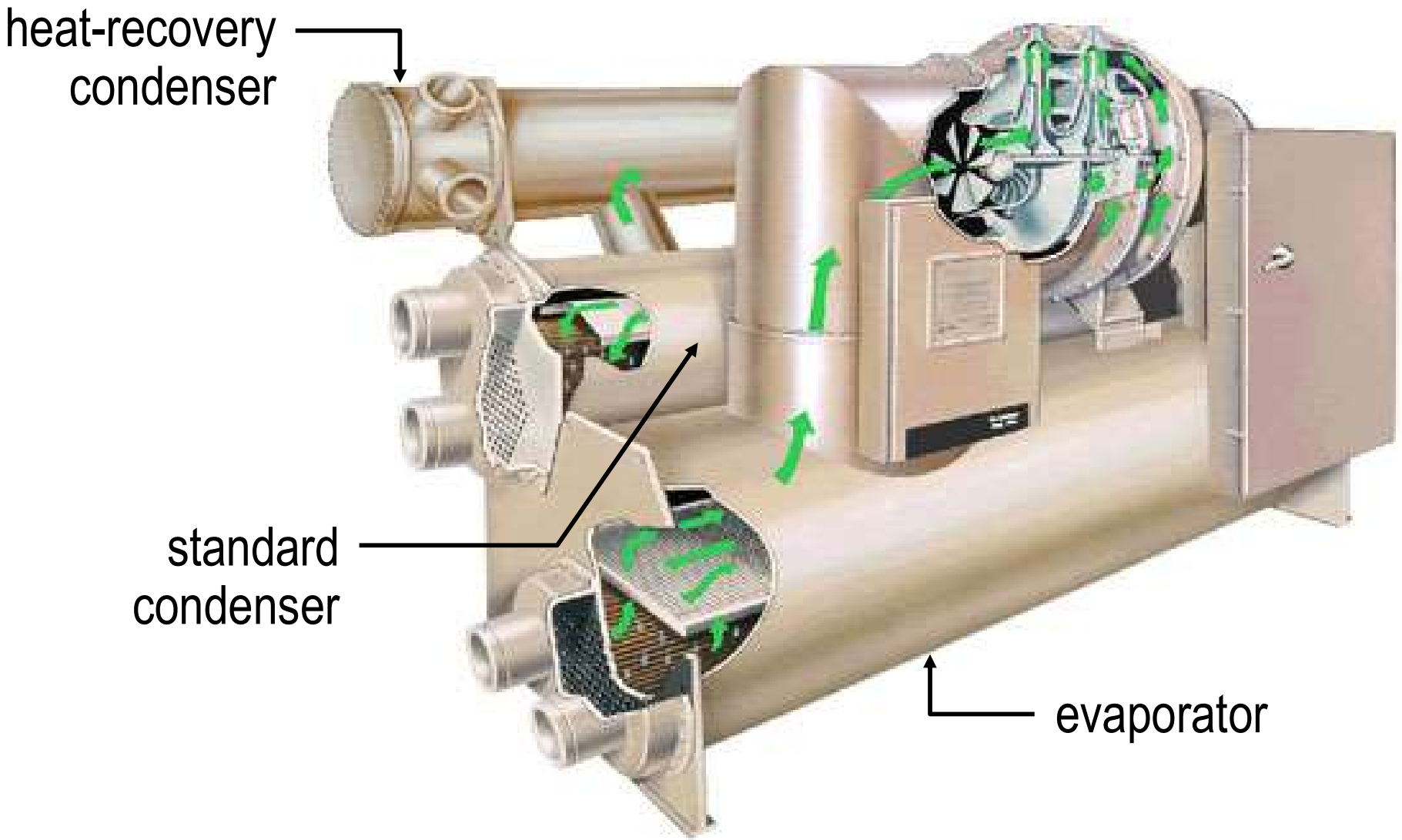
Preferential Chiller Loading



Sidestream Configuration



Heat-Recovery Chiller



Heat-Recovery Chiller Options

heat-recovery (dual) condenser

- Second, full-size condenser
- Large heating loads
- High hot-water temperatures
- Controlled
- Degrades chiller efficiency

auxiliary condenser

- Second, smaller-size condenser
- Preheating loads
- Moderate hot-water temperatures
- Uncontrolled
- Improves chiller efficiency

heat pump

- No extra condenser
- Large base-heating loads or continuous operation
- High hot-water temperatures
- Controlled
- Good heating efficiency

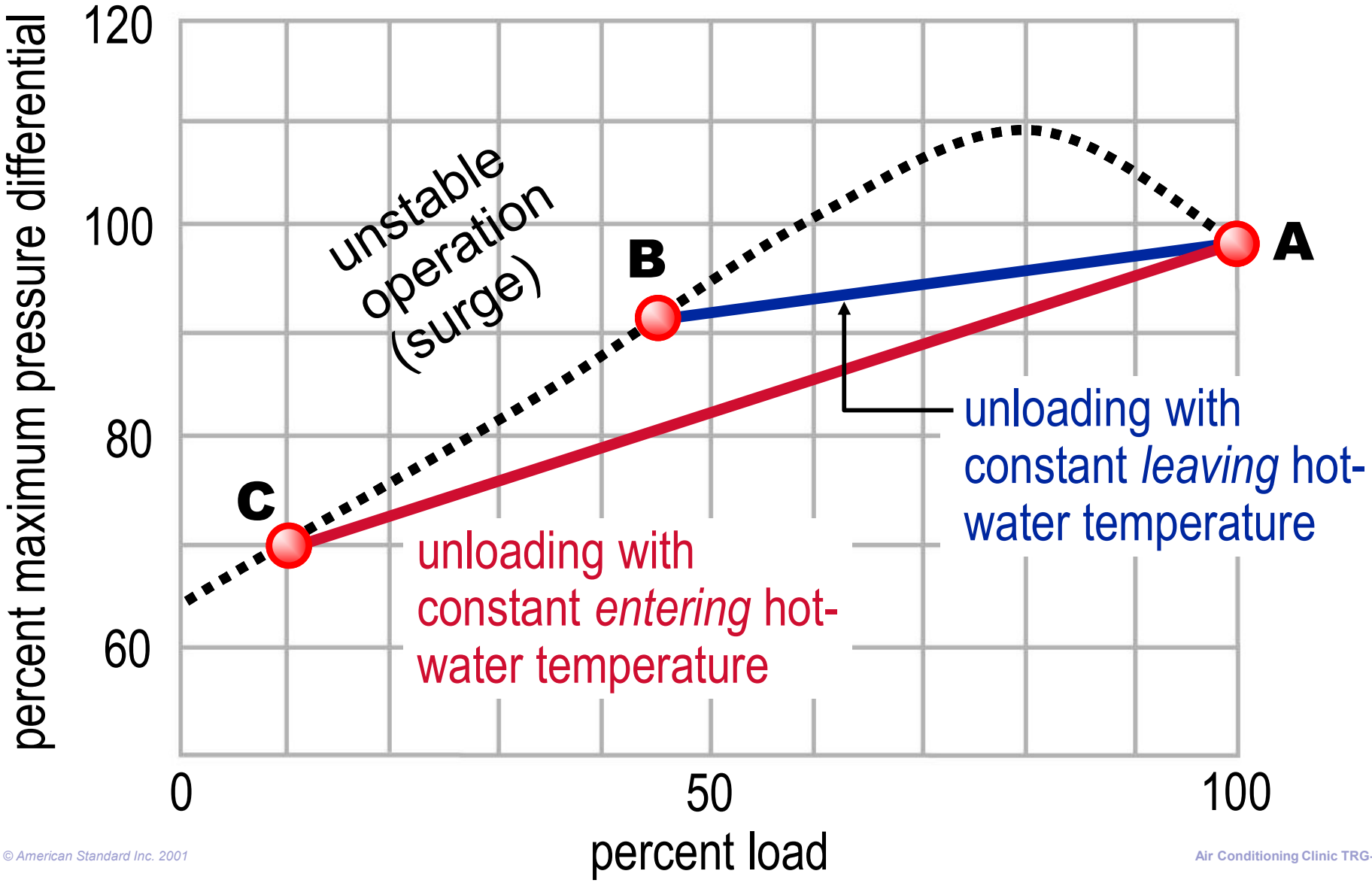
Heat-Recovery Chiller Efficiency

chiller type	cooling mode	heat-recovery mode
cooling-only centrifugal chiller	0.57 kW/ton [6.2 COP]	not applicable
heat-recovery centrifugal chiller	0.60 kW/ton [5.9 COP]	0.69 kW/ton [5.1 COP]

cooling mode conditions:
- evaporator ΔT = 44°F to 54°F [6.7°C to 12.2°C]
- condenser ΔT = 85°F to 95°F [29.4°C to 35.0°C]

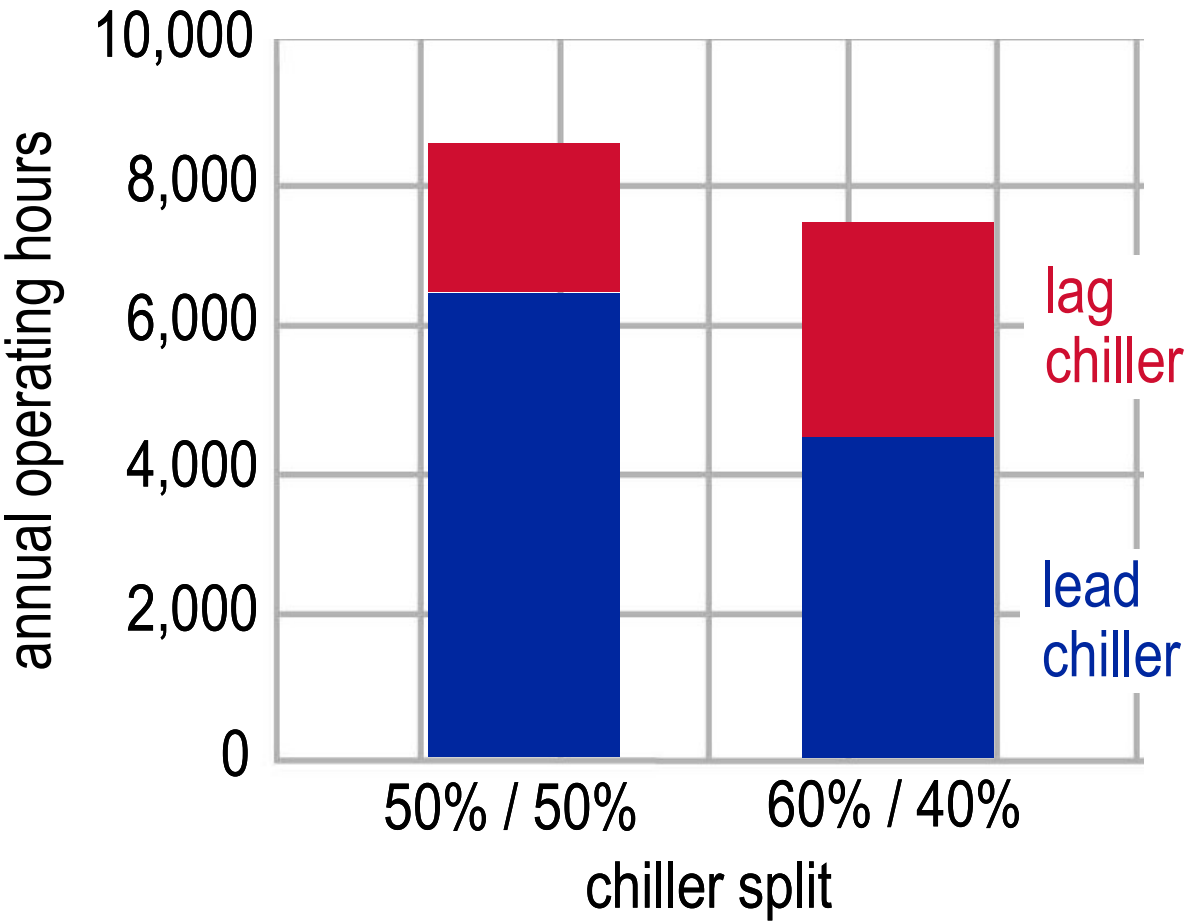
heat-recovery mode conditions:
- evaporator ΔT = 44°F to 54°F [6.7°C to 12.2°C]
- condenser ΔT = 85°F to 105°F [29.4°C to 40.6°C]

Control of a Heat-Recovery Chiller

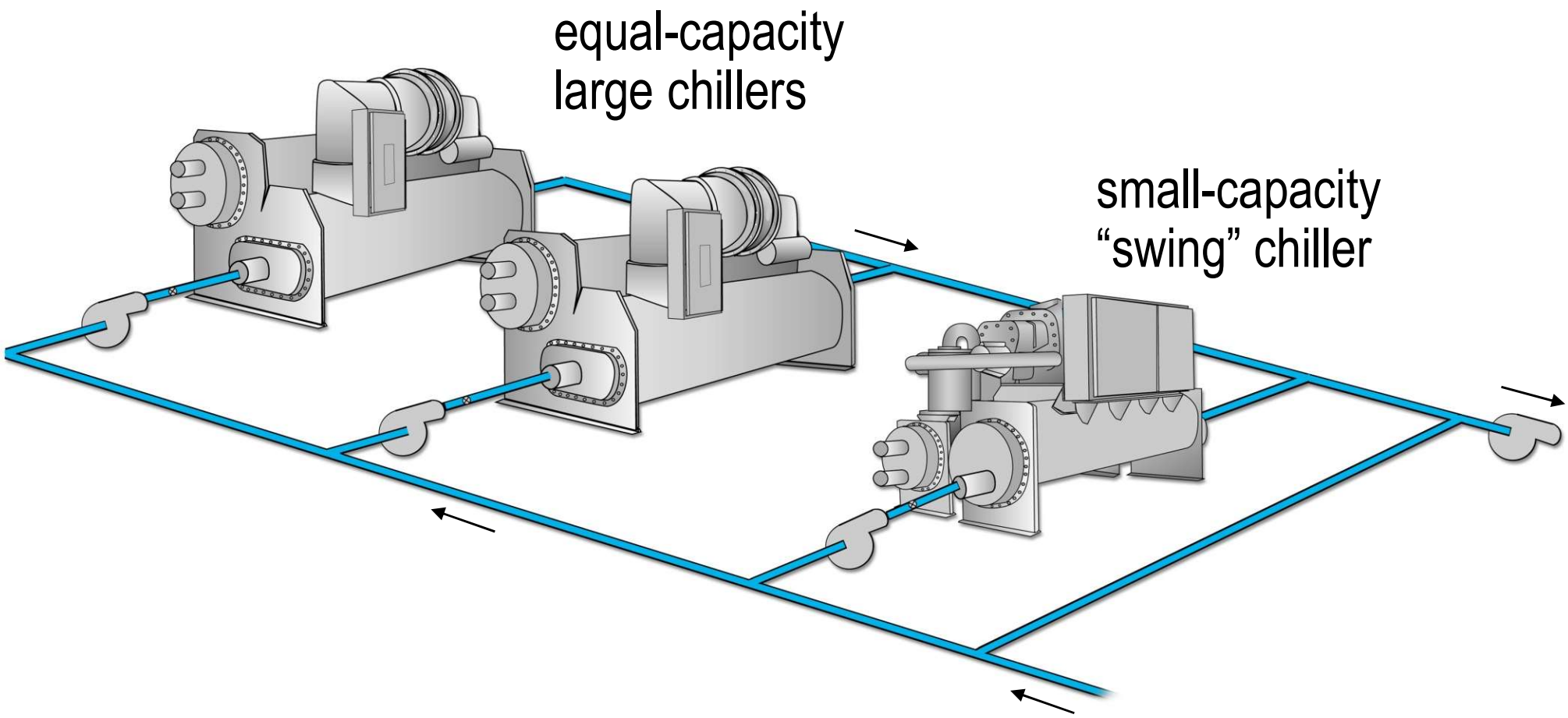


Asymmetric Design

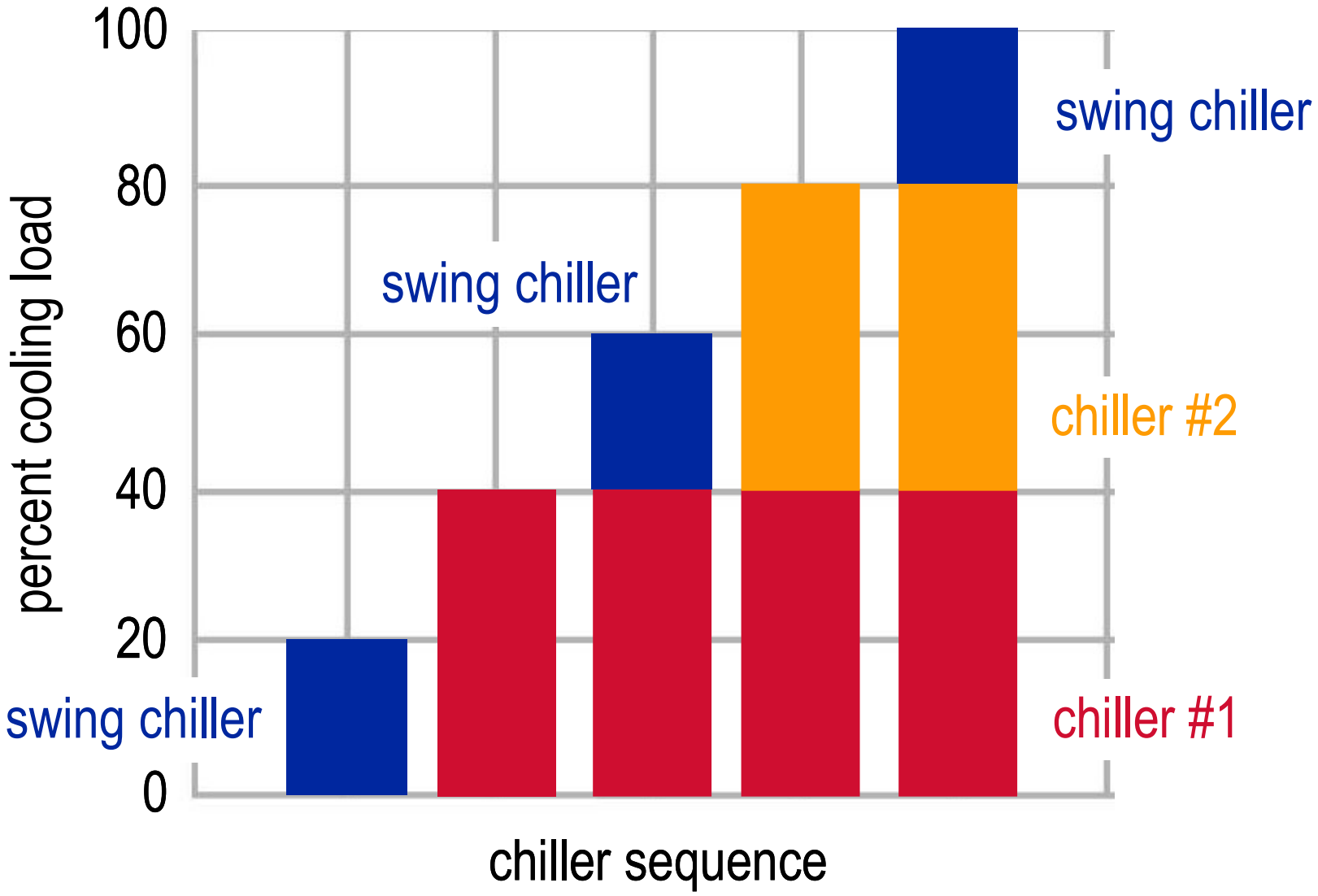
- Different chiller capacities
- Different chiller efficiencies



Swing Chiller



Swing Chiller

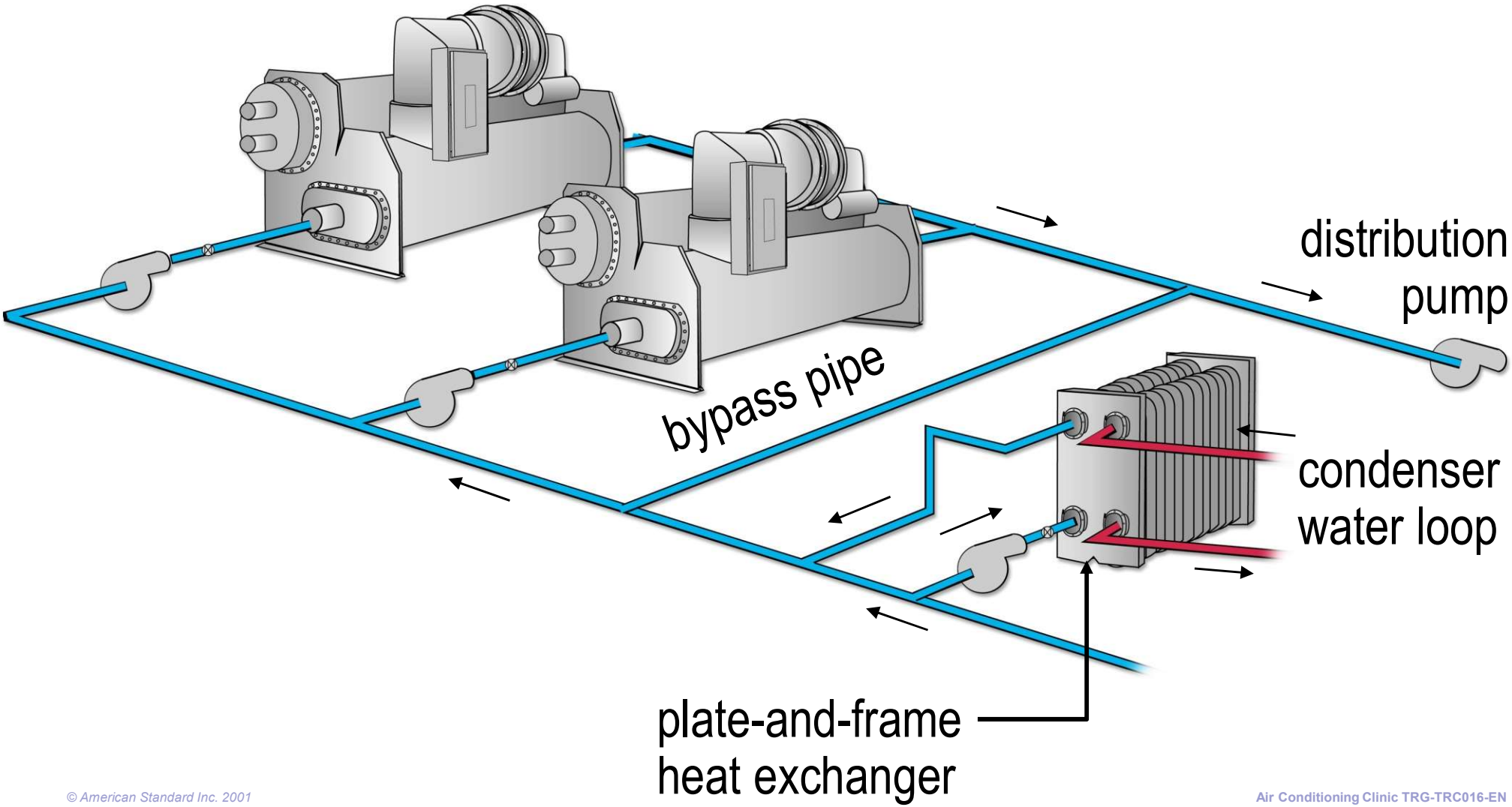


“Free” Cooling

- **Airside economizer**
- **Waterside economizer**
  - Strainer cycle
  - Plate-and-frame heat exchanger
  - Refrigerant migration

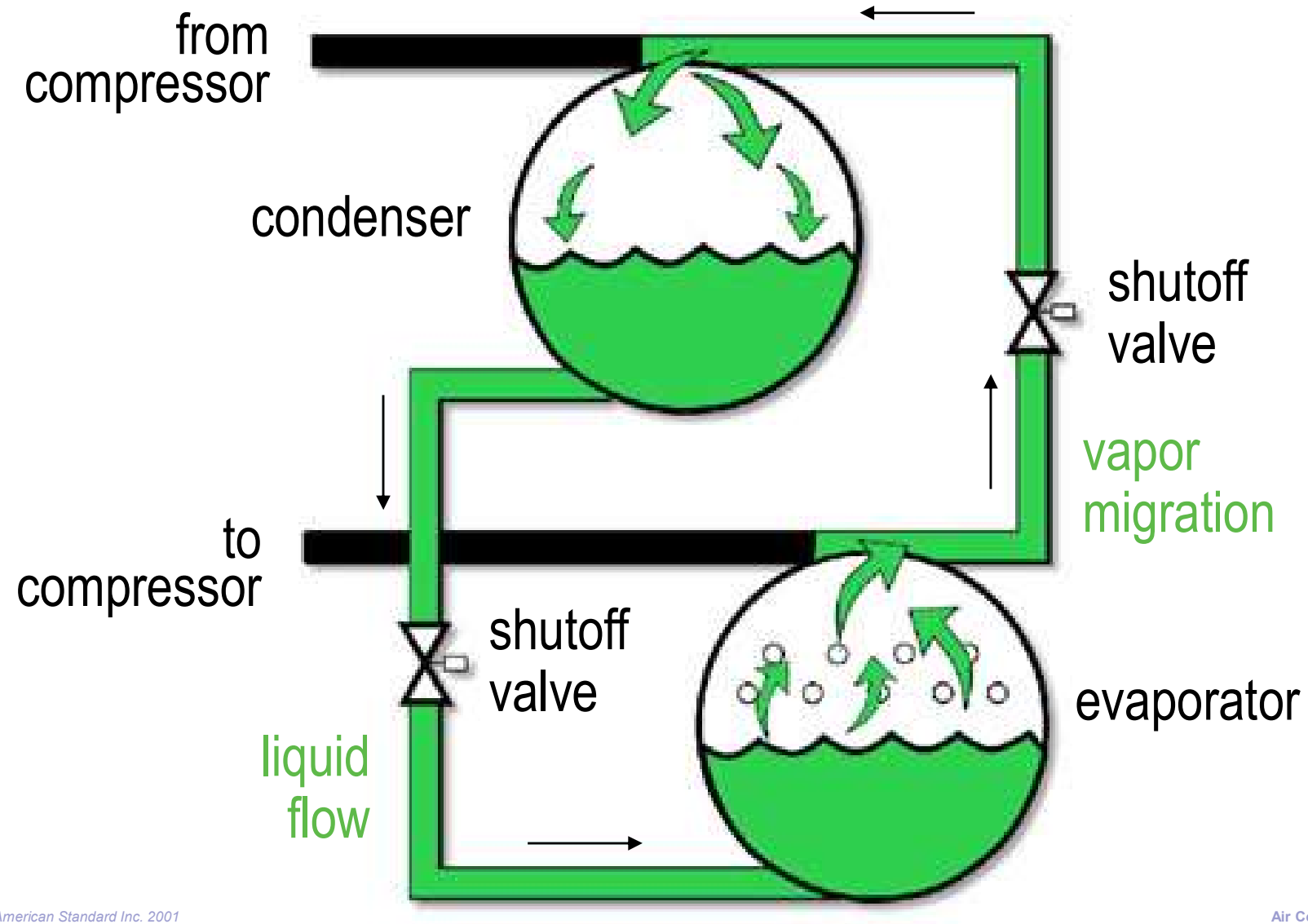
waterside economizer

Plate-and-Frame Heat Exchanger

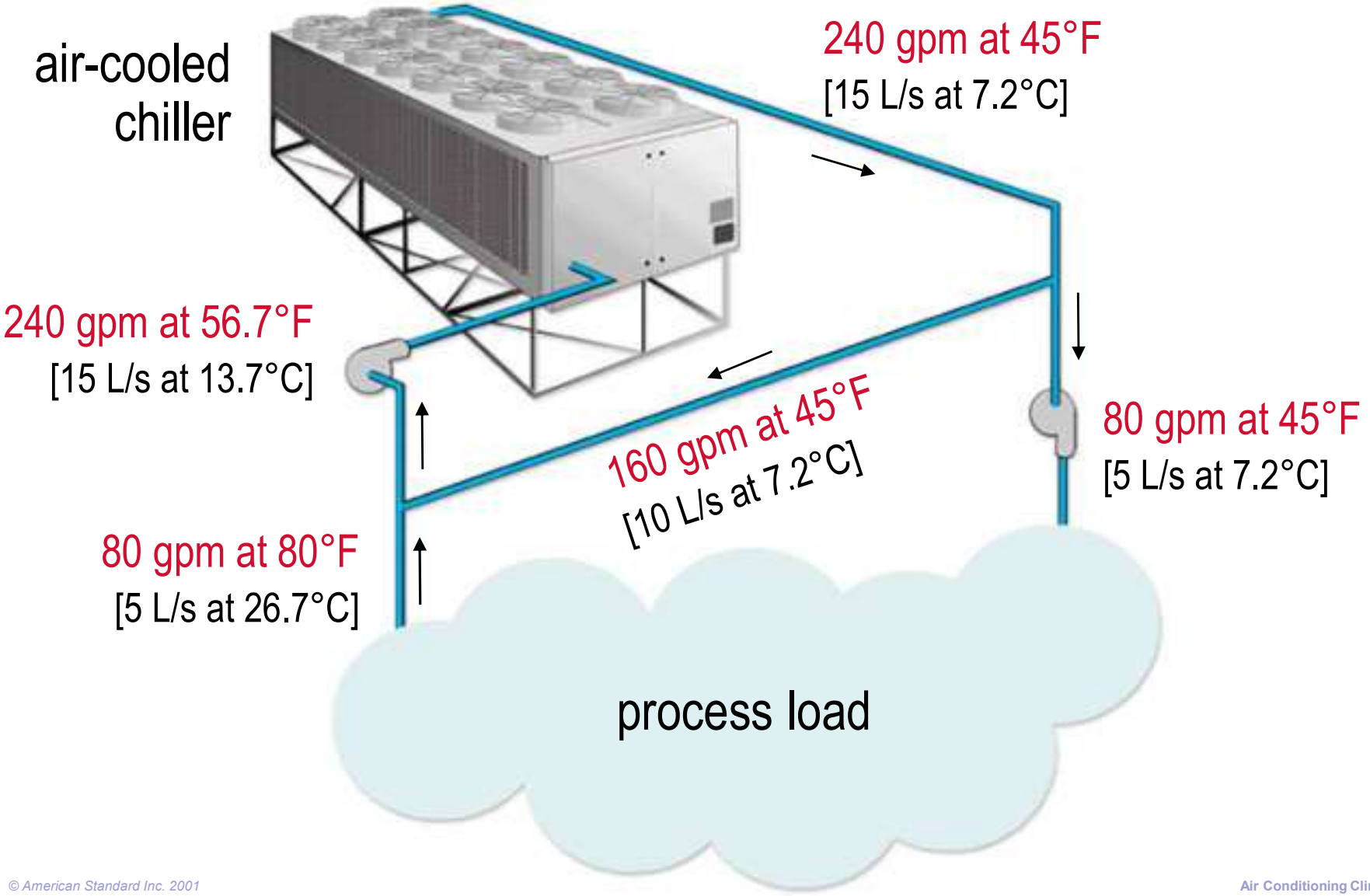


waterside economizer

Refrigerant Migration



Application Outside Range of Chiller



Chilled-Water Systems

period four

Chiller-Plant Control

Chiller Controls

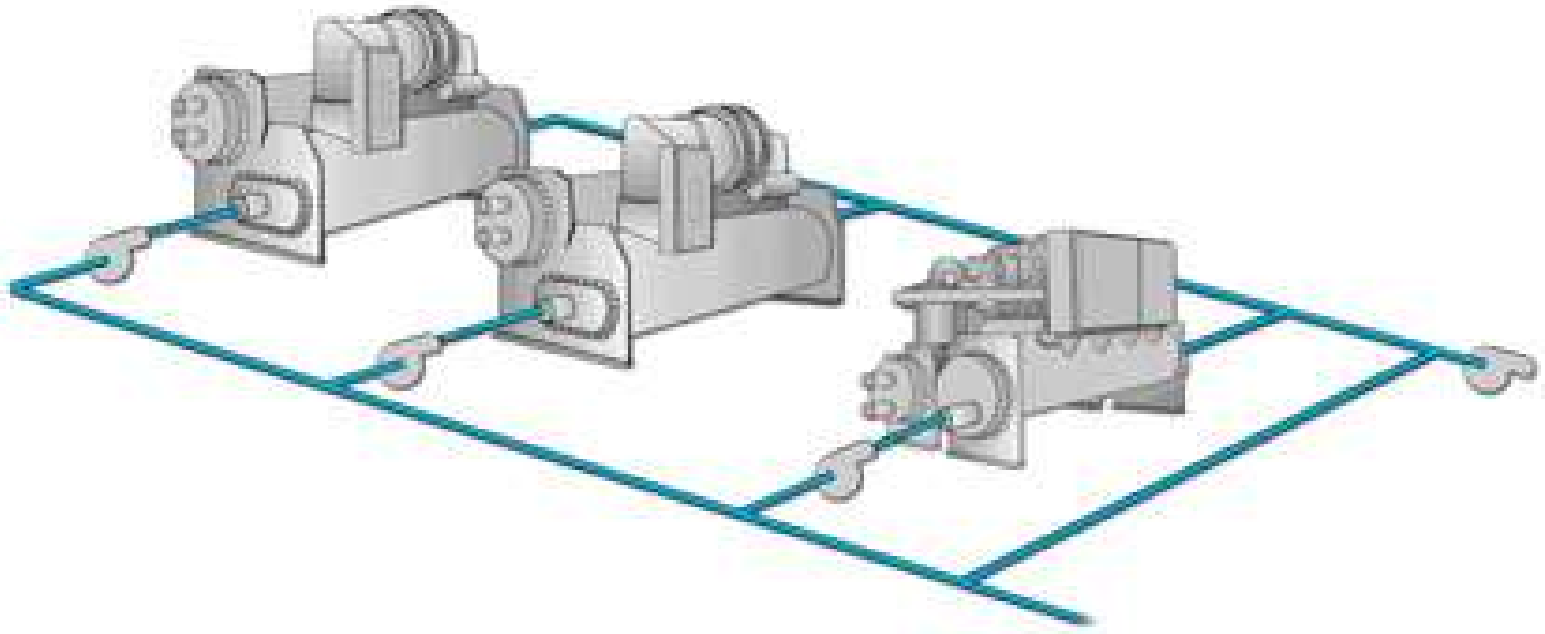
- Start–stop
- Chilled-water temperature control
- Monitor and protect
- Adapt to unusual conditions

Key Issues for Chiller-Plant Control

- When to turn a chiller on or off?
- Which chiller to turn on or off?
- How to recover from an equipment failure?
- How to optimize system efficiency?
- How to communicate with the operator?

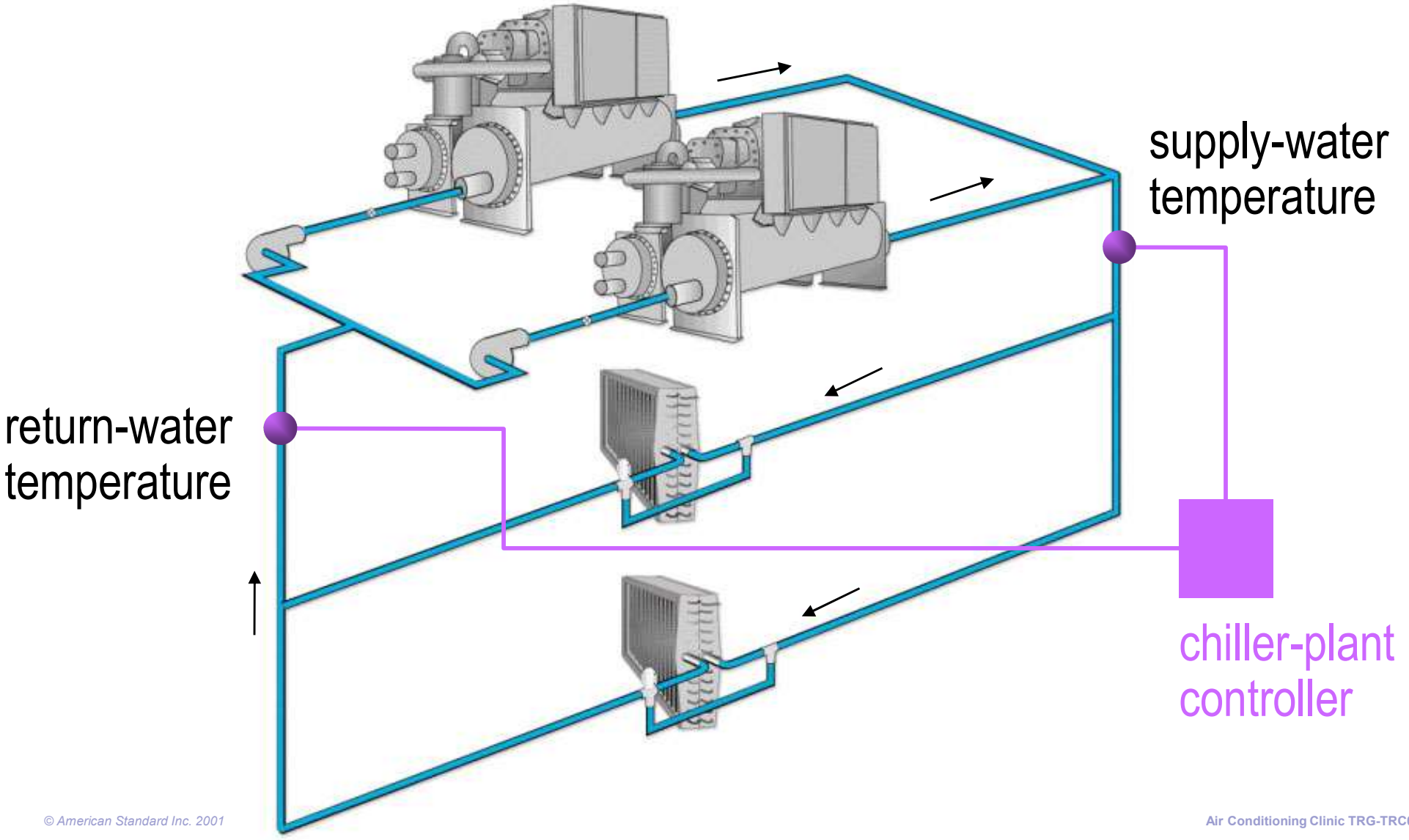
Chiller Sequencing

- Turning on an additional chiller
- Turning off a chiller
- Which chiller to turn on or off?



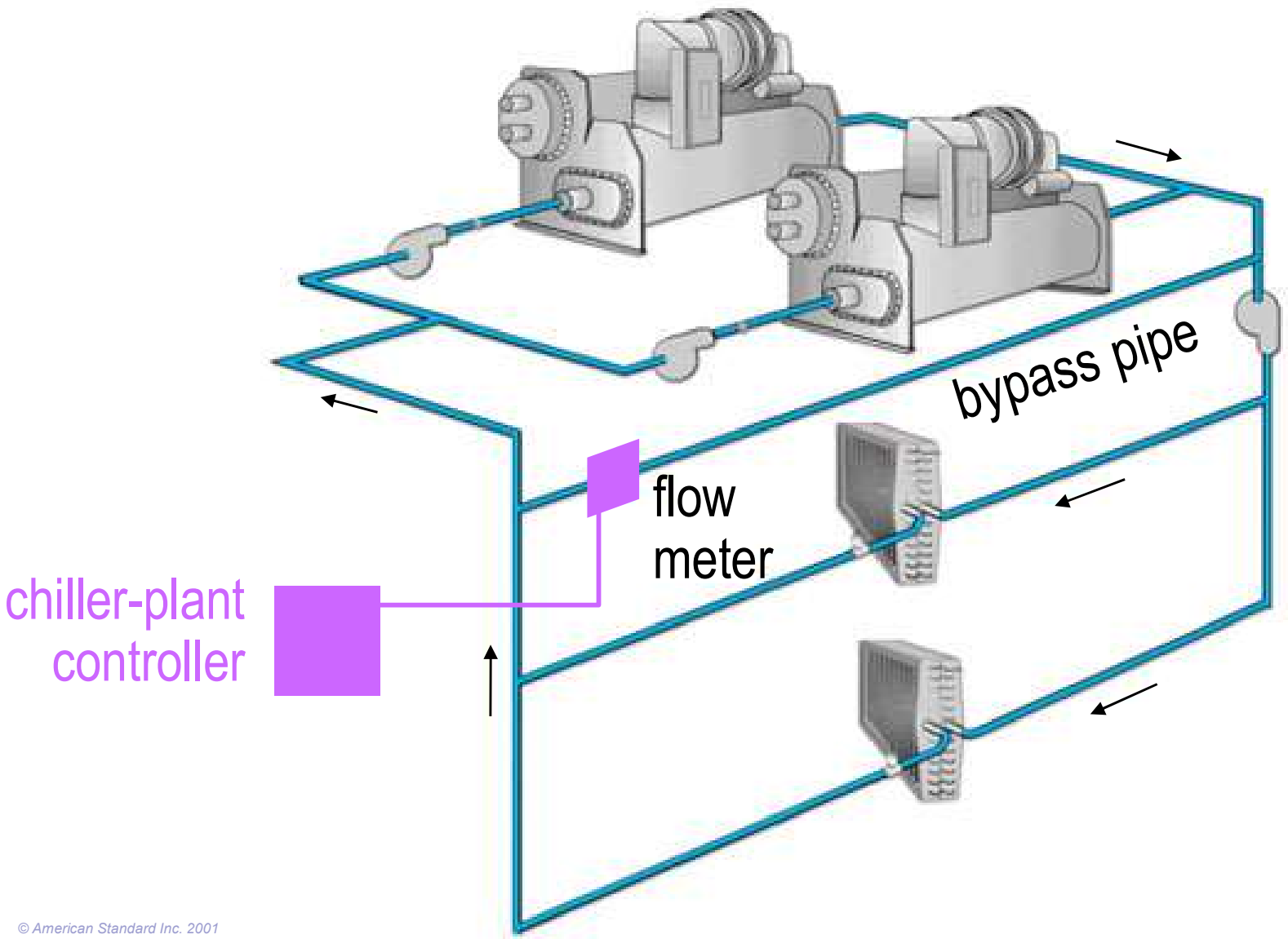
load indicators

Temperature



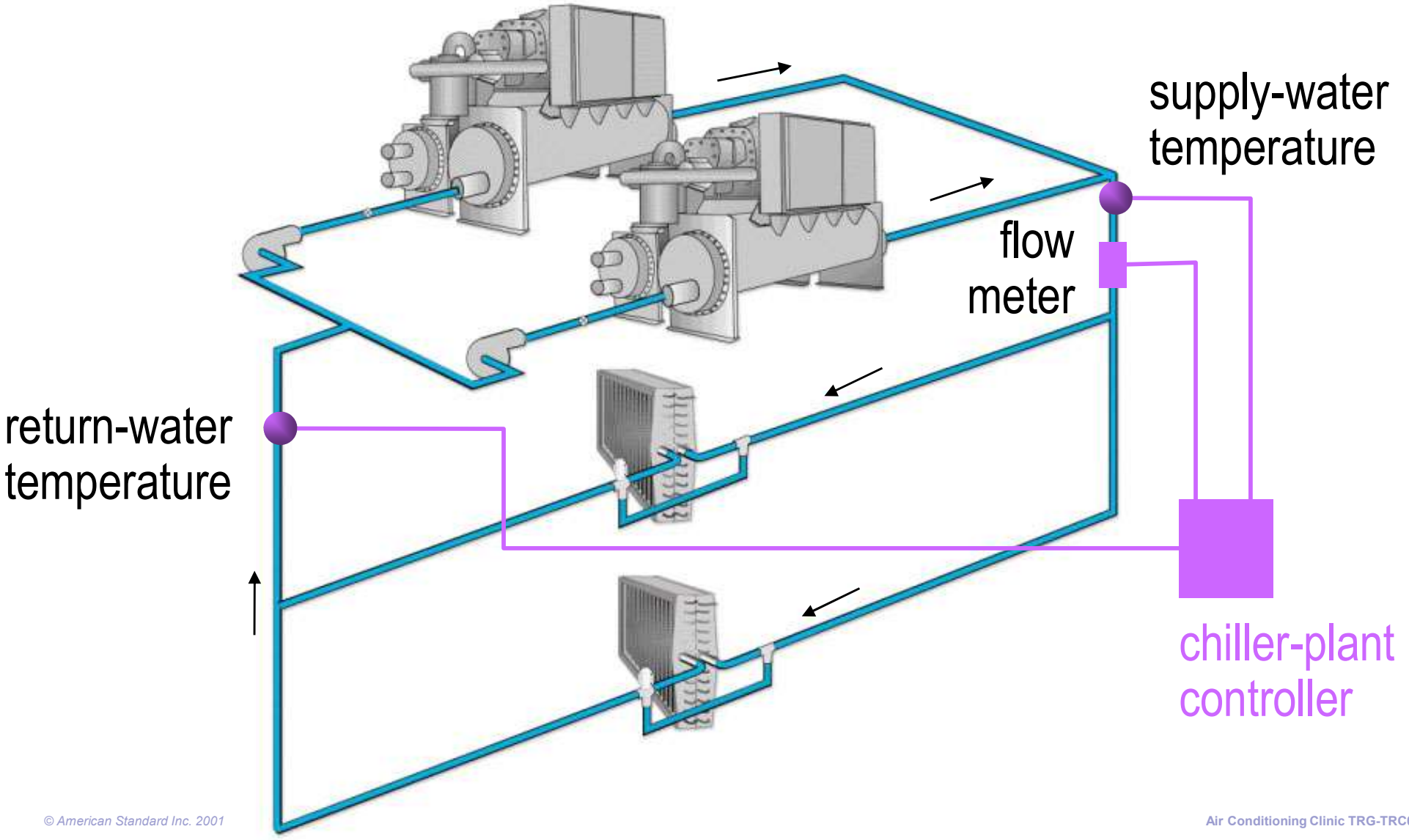
load indicators

Flow

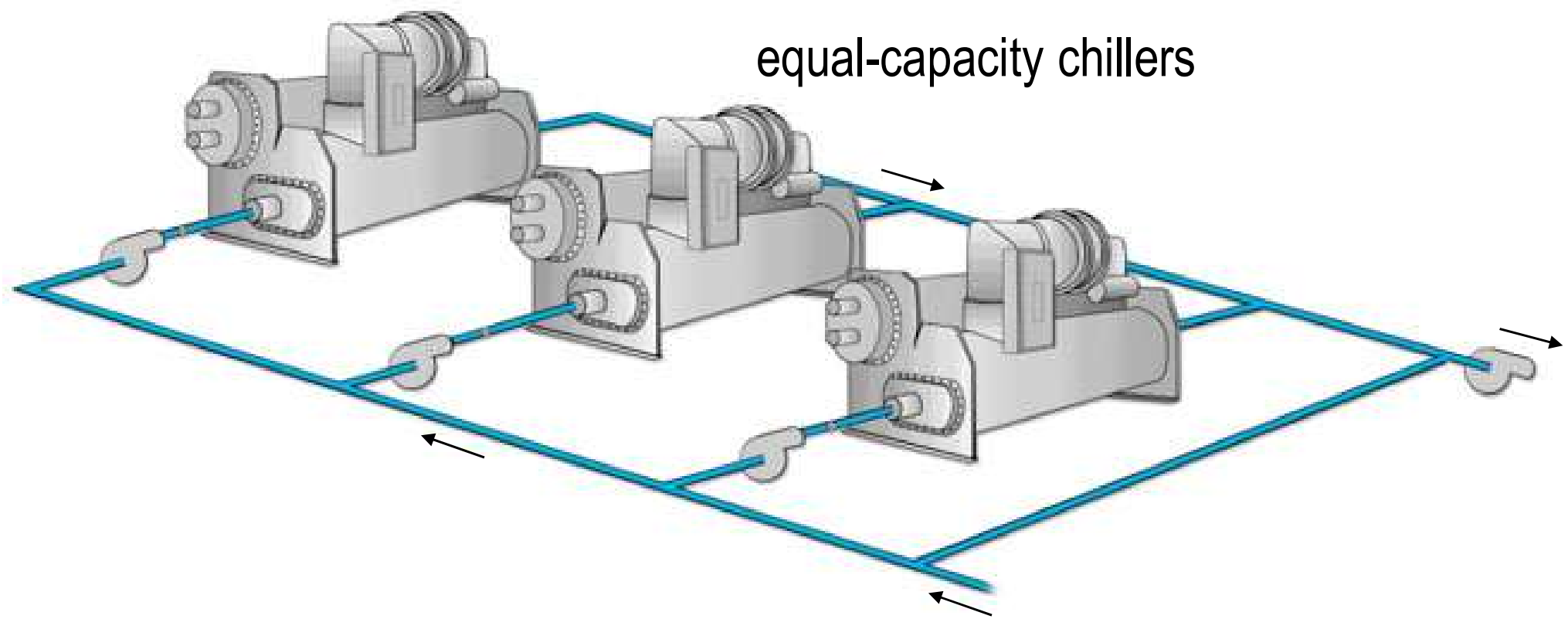


load indicators

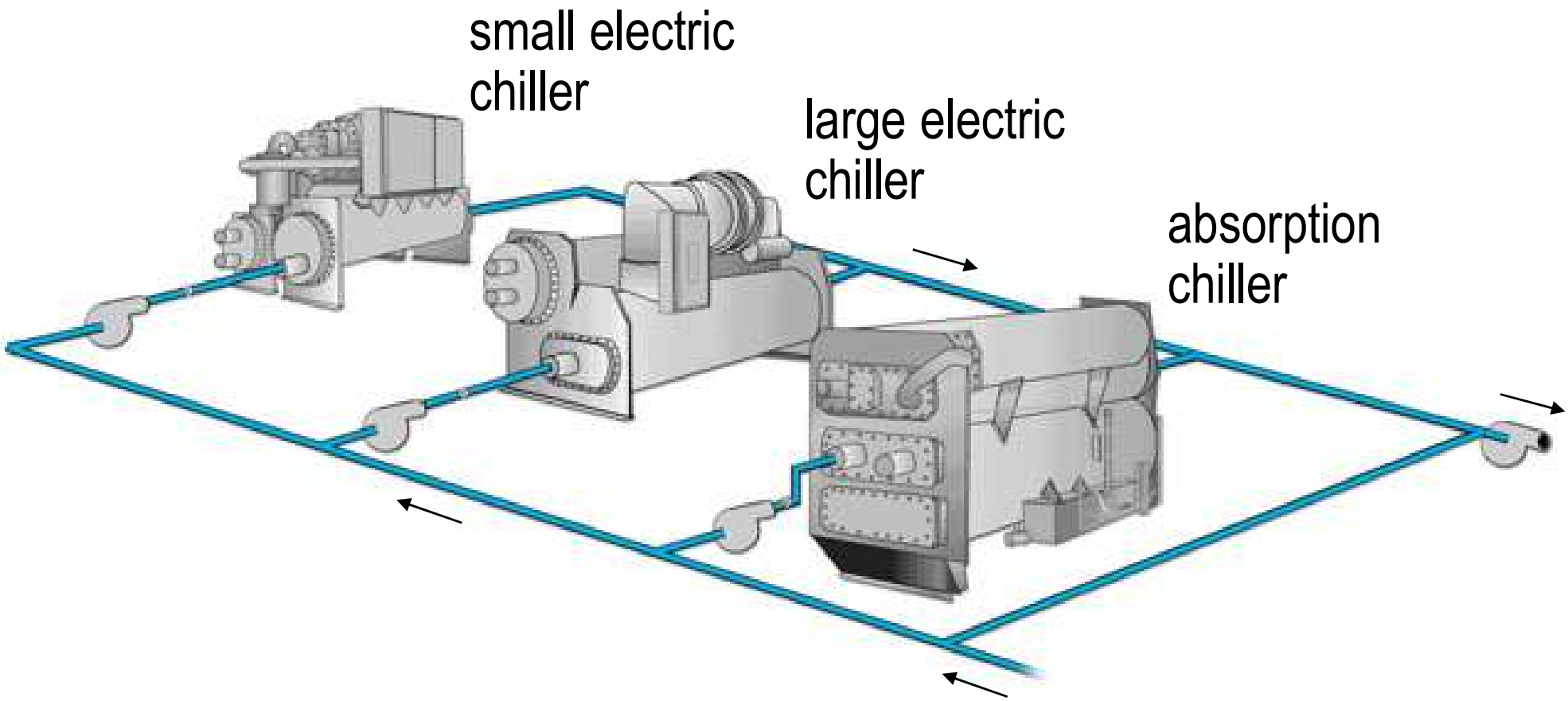
Capacity



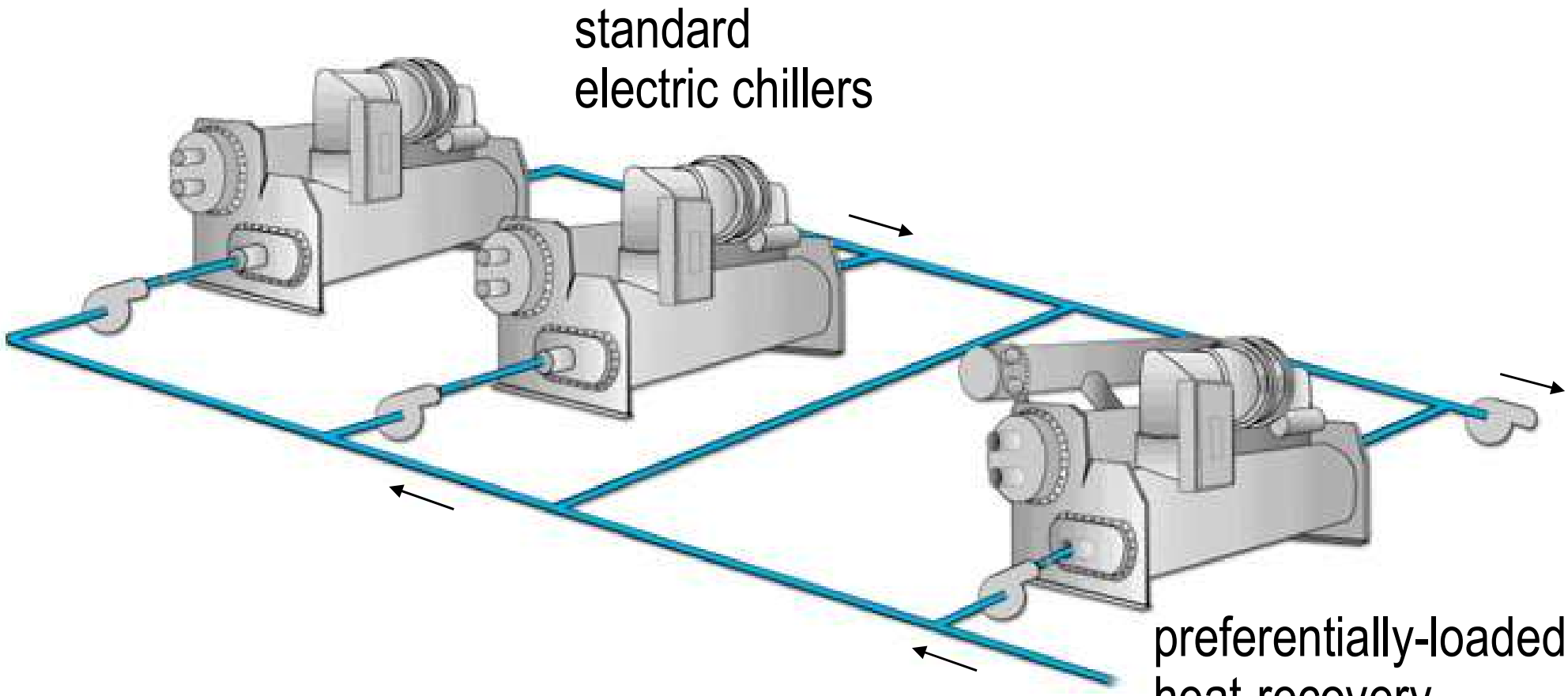
Chiller Rotation



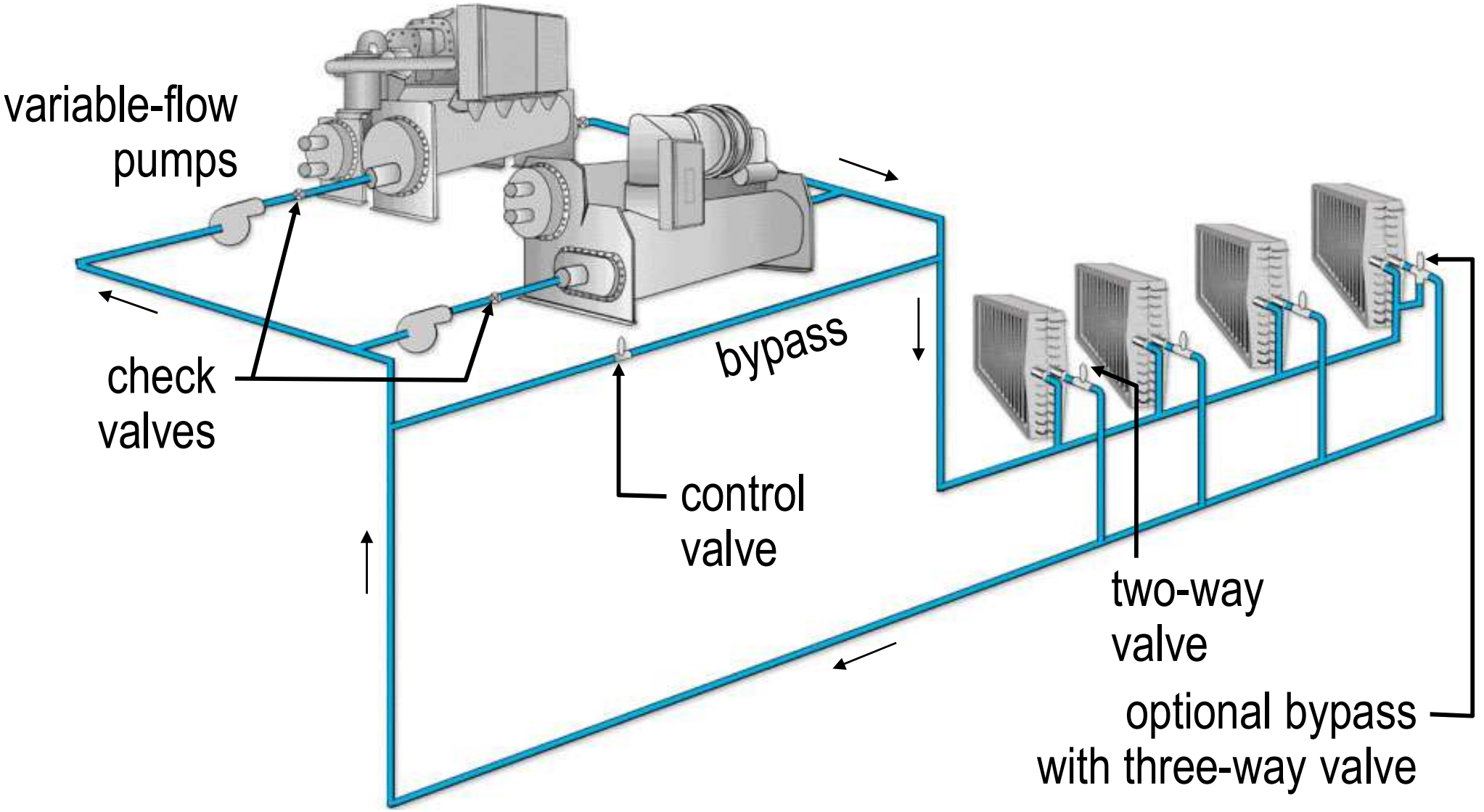
Chiller Rotation



Heat Recovery



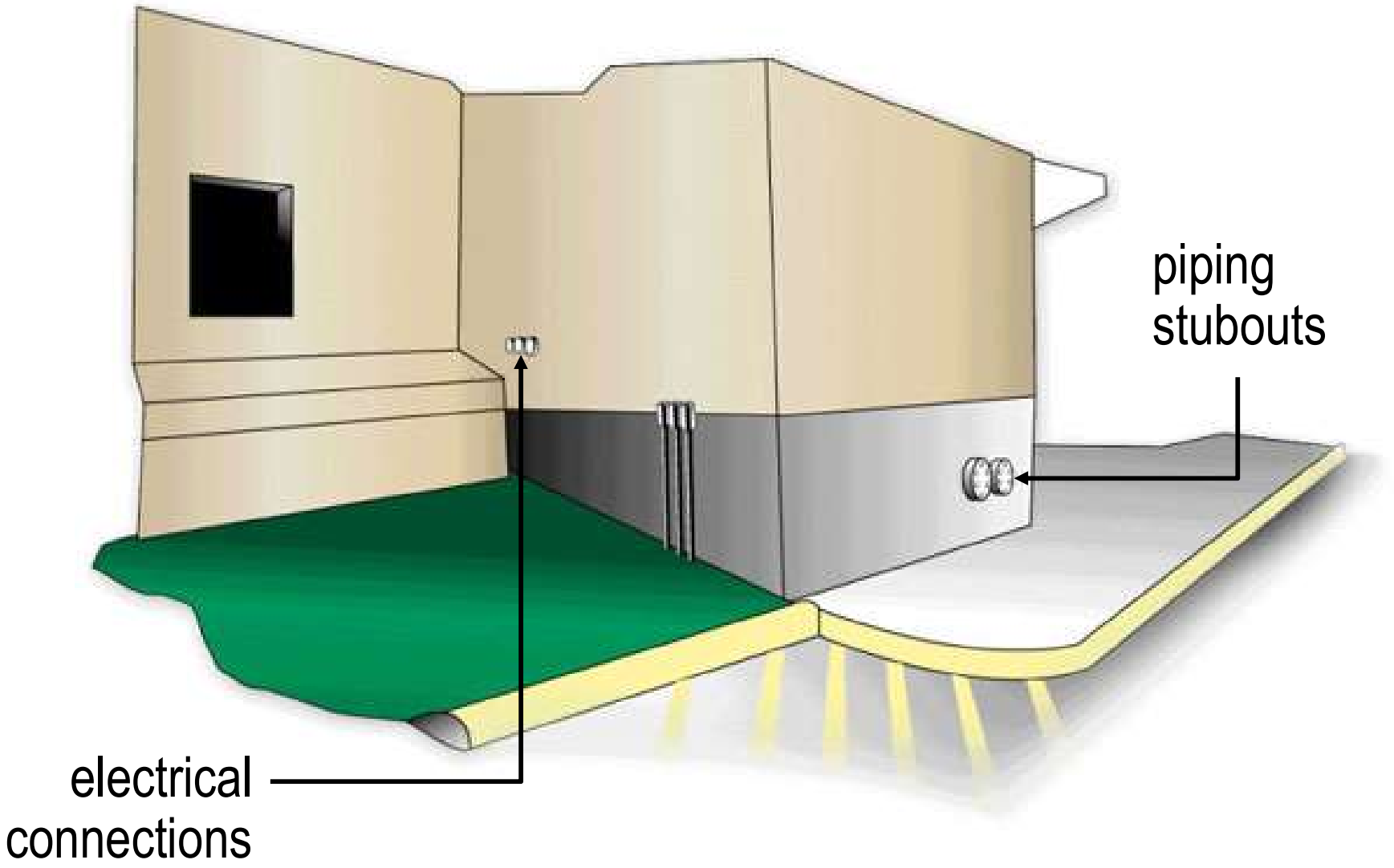
Variable-Primary-Flow Systems



System Failure Recovery

- **Maintain flow of chilled water**
- **Keep it simple**
  - Lock out failed equipment
  - Turn on the next chiller in the sequence
- **Notify the operator**
- **Allow the operator to intervene**

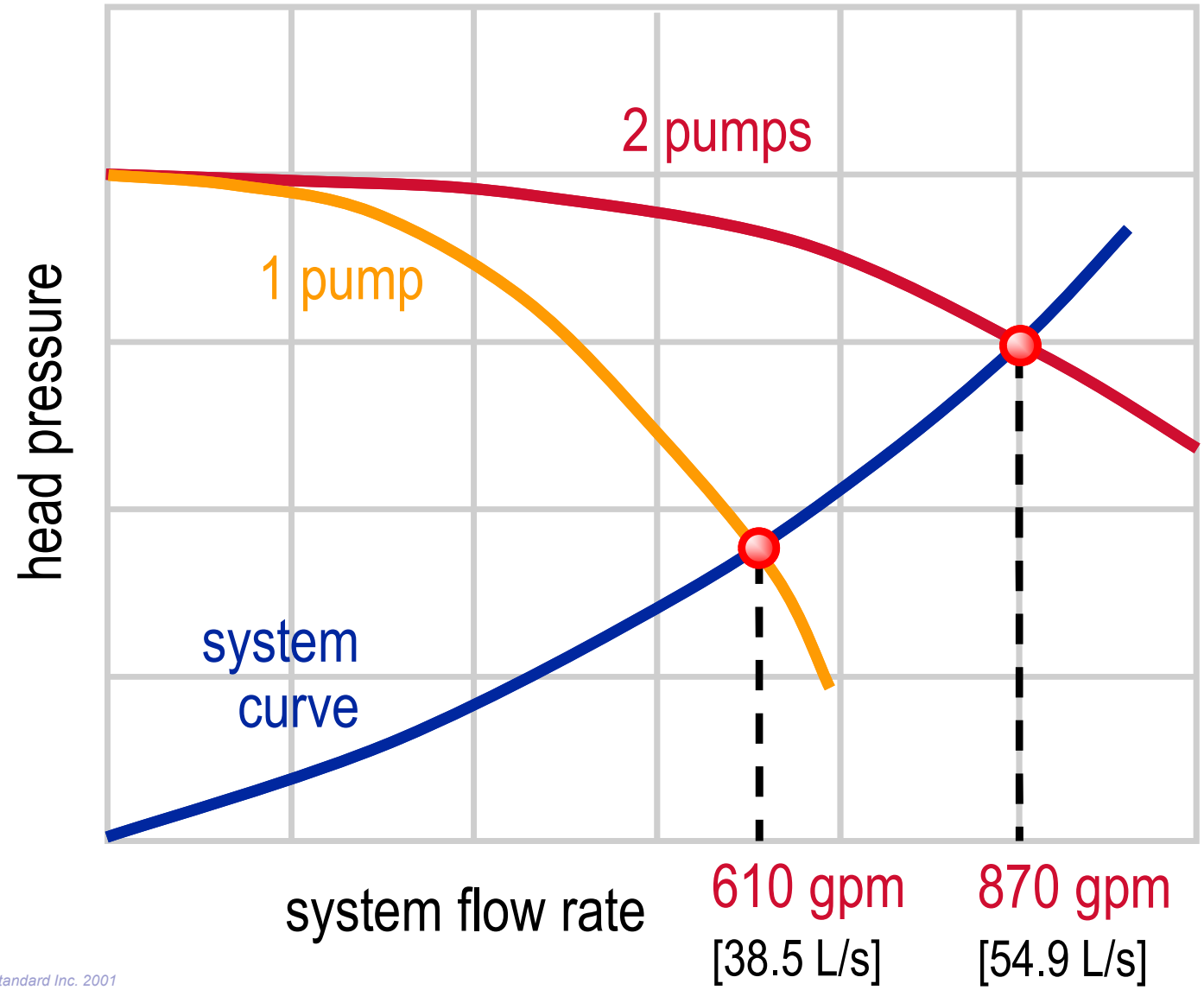
Contingency Planning



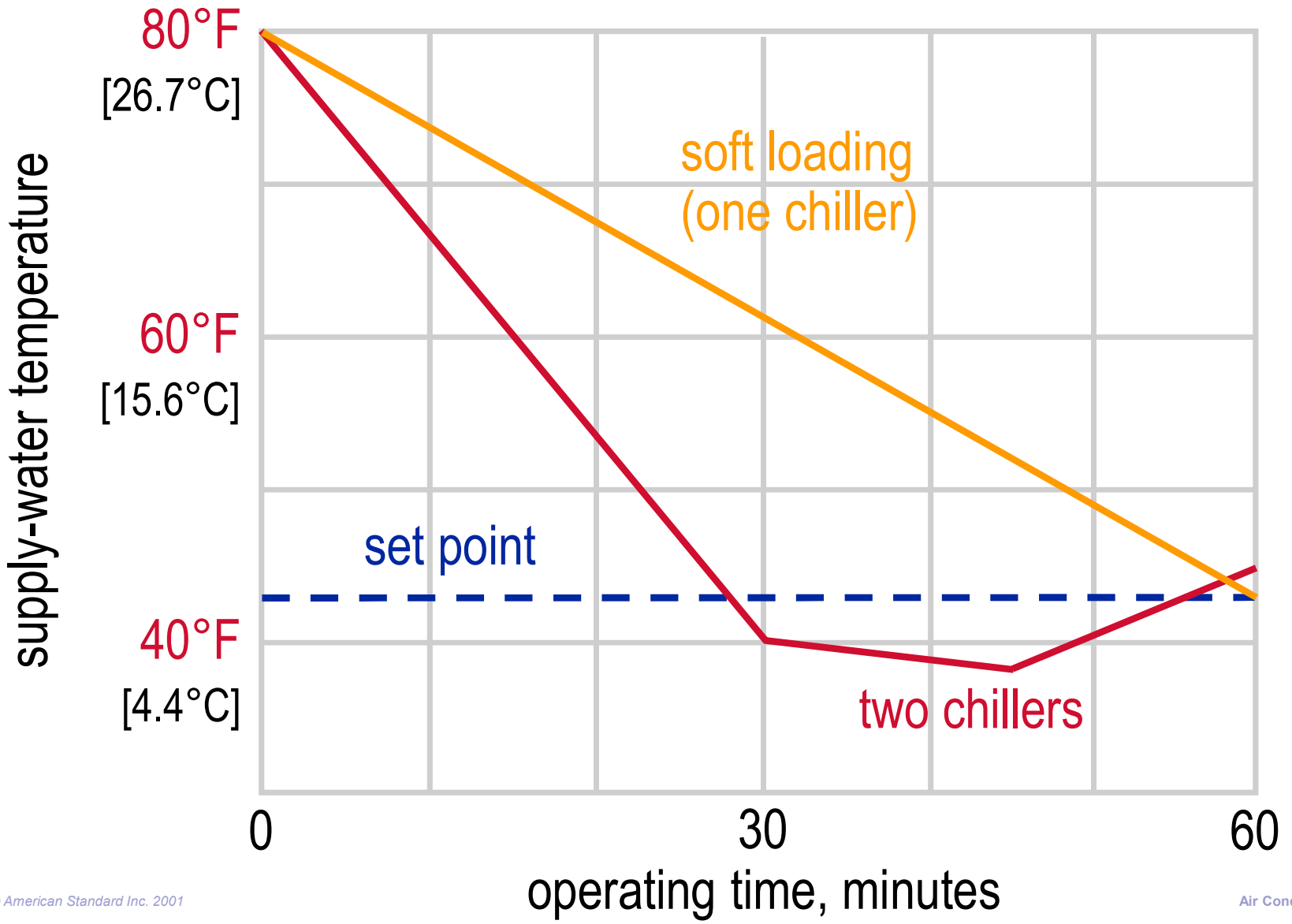
System Timers

- **Load-confirmation timer**
  - Avoids transient conditions
- **Staging-interval timer**
  - Allows time for the system to respond to turning a chiller on
- **Minimum-cycle timer**
  - Prevents excessive cycling

Unload Before Start

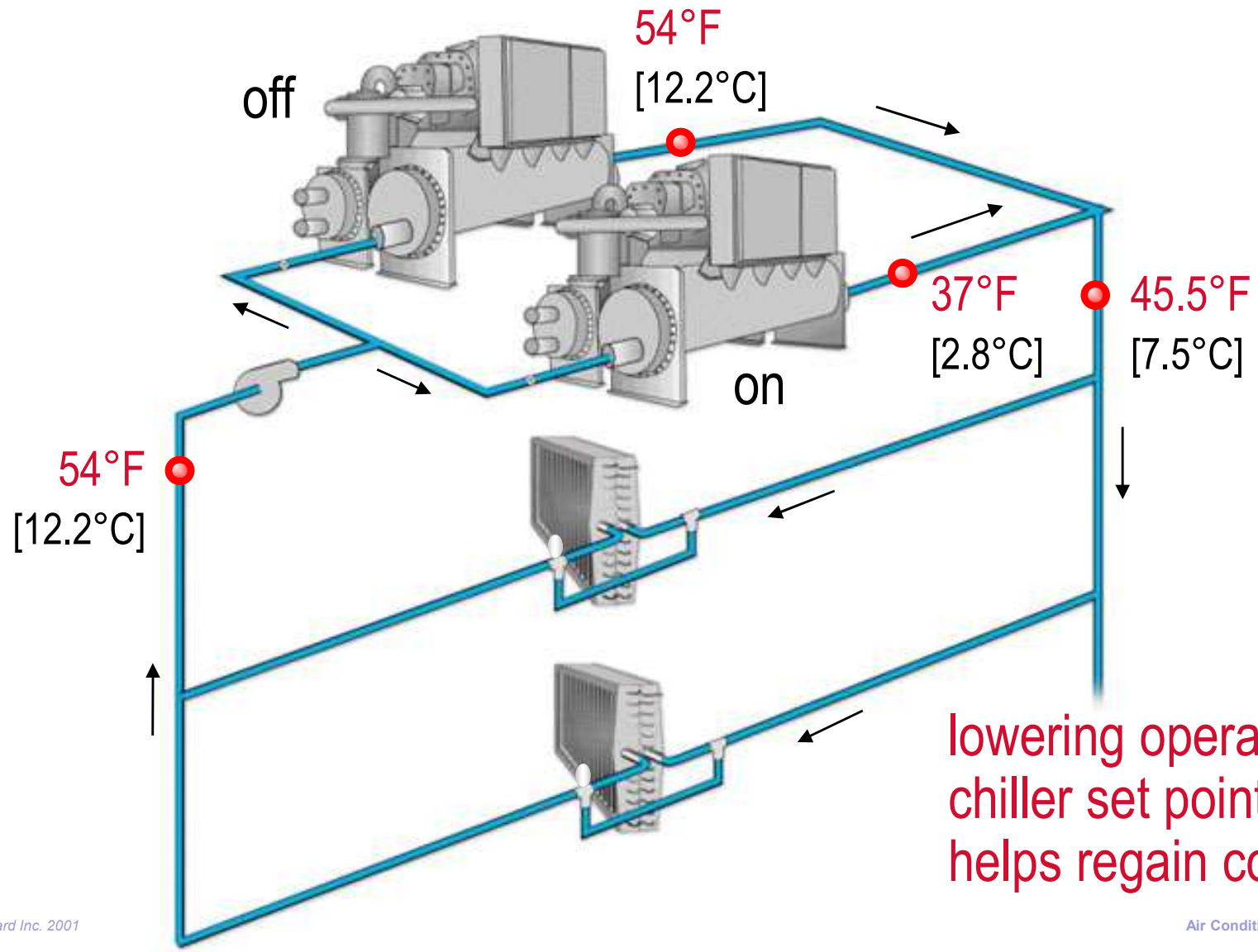


Soft Loading



constant-volume pumping system

Chilled-Water Set Point Control



lowering operating chiller set point helps regain control

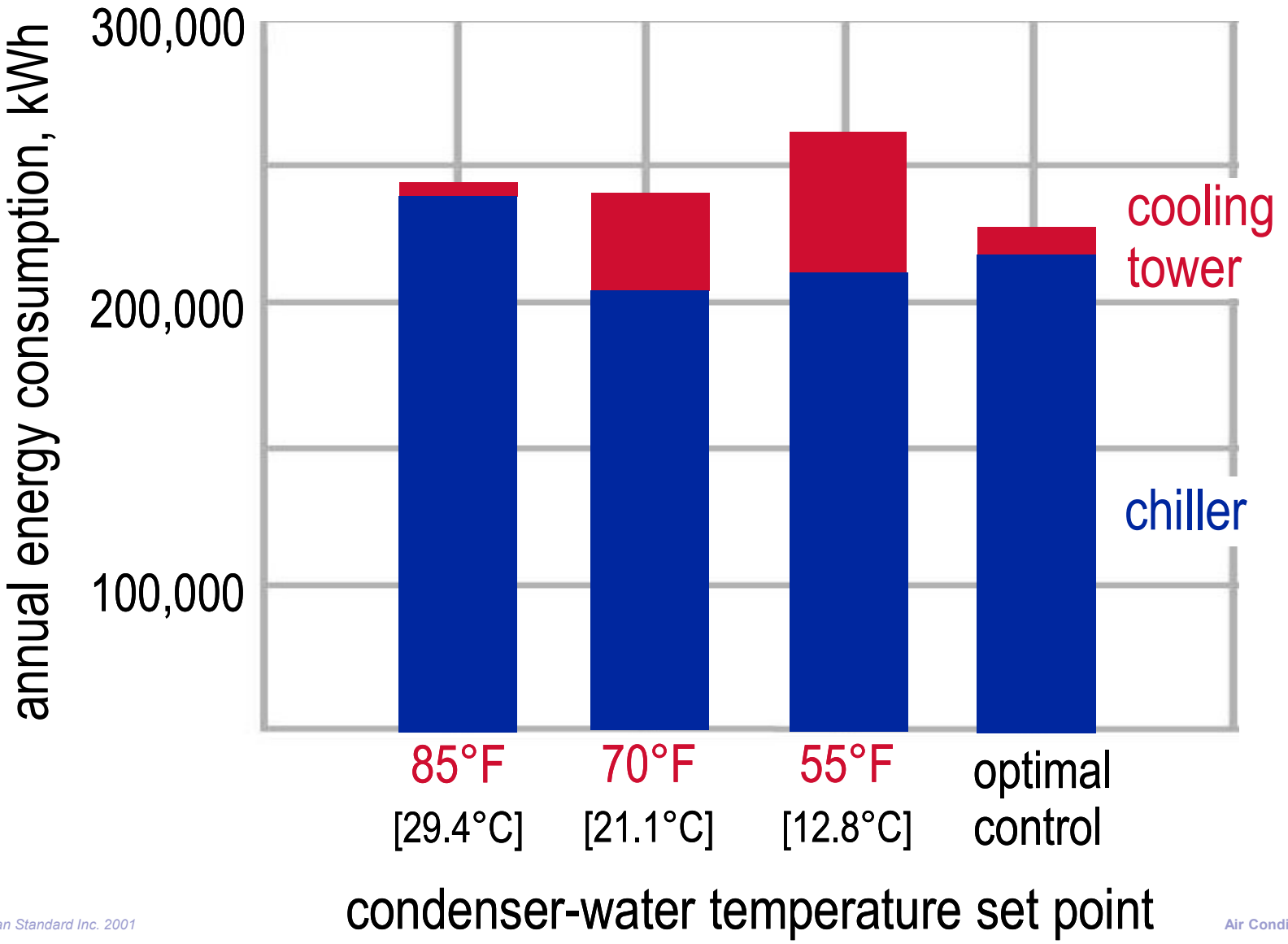
System Optimization

- **Chiller**
  - Decrease condenser-water temperature
  - Increase chilled-water temperature
- **Chilled-water pump (variable-flow system)**
  - Increase chilled-water ΔT
- **Cooling tower**
  - Increase condenser-water temperature
- **Condenser-water pump (variable-flow system)**
  - Increase condenser-water ΔT

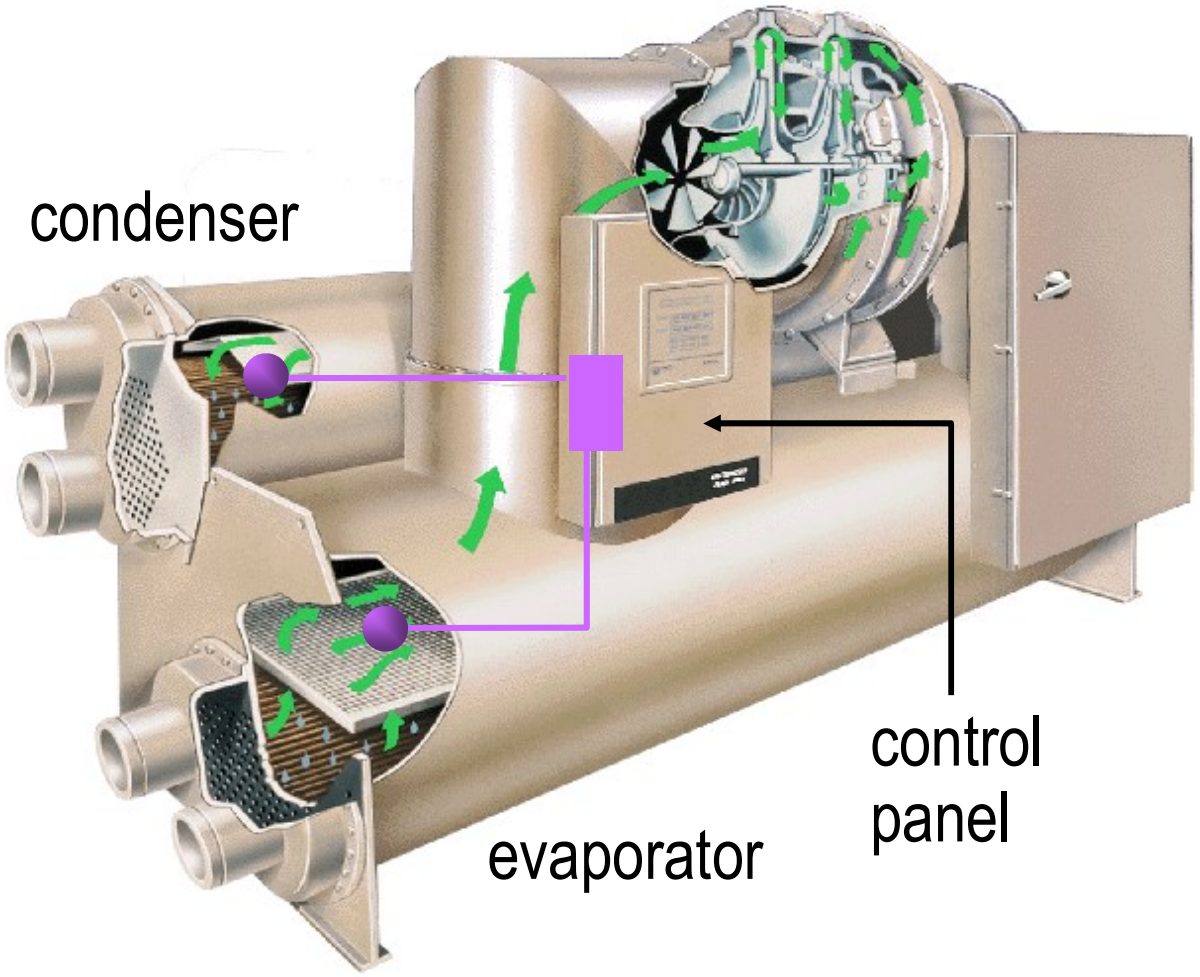
Chilled Water Reset

- **Pros**
  - Reduces chiller energy
  - Can work in constant-flow systems
- **Cons**
  - Increases pump energy in variable-flow systems
  - Can cause loss of space humidity control
  - Complicates chiller sequencing control

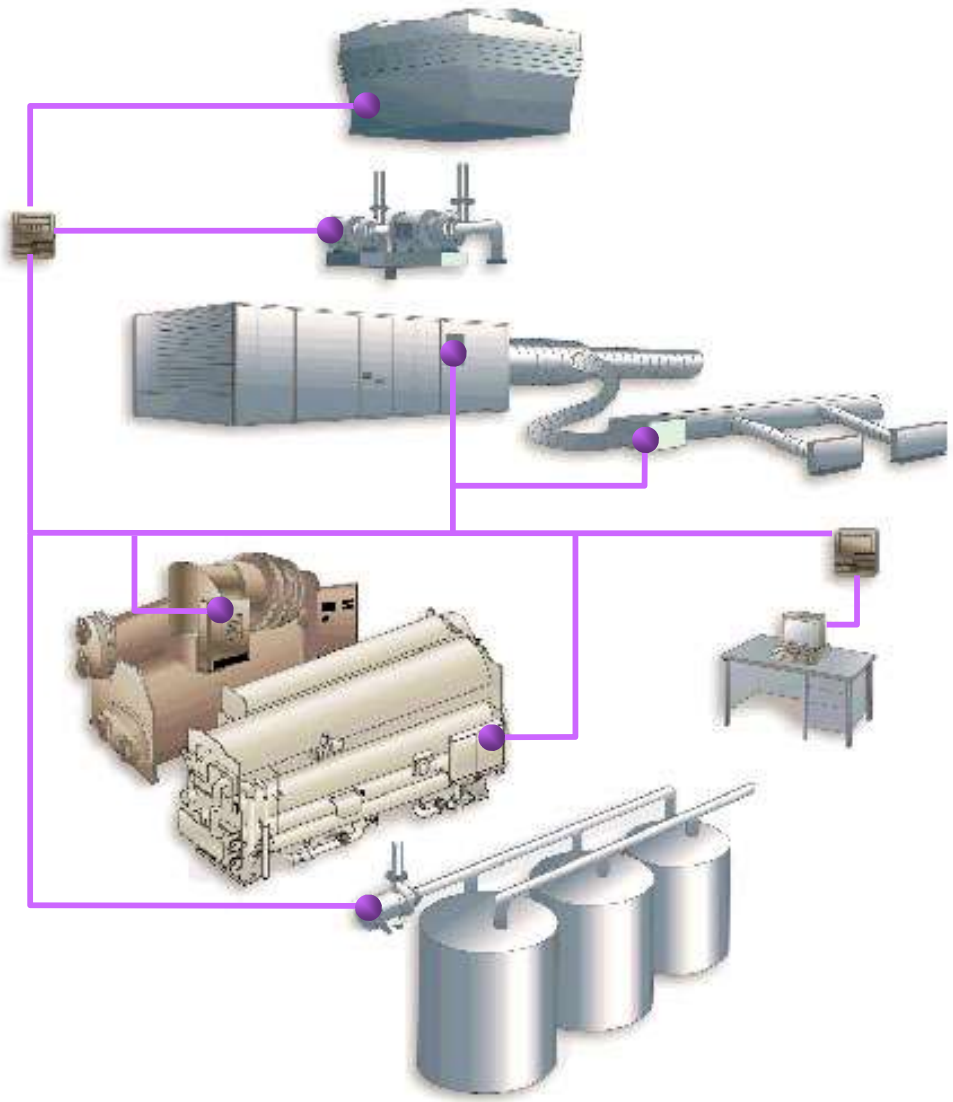
Condenser-Water Temperature



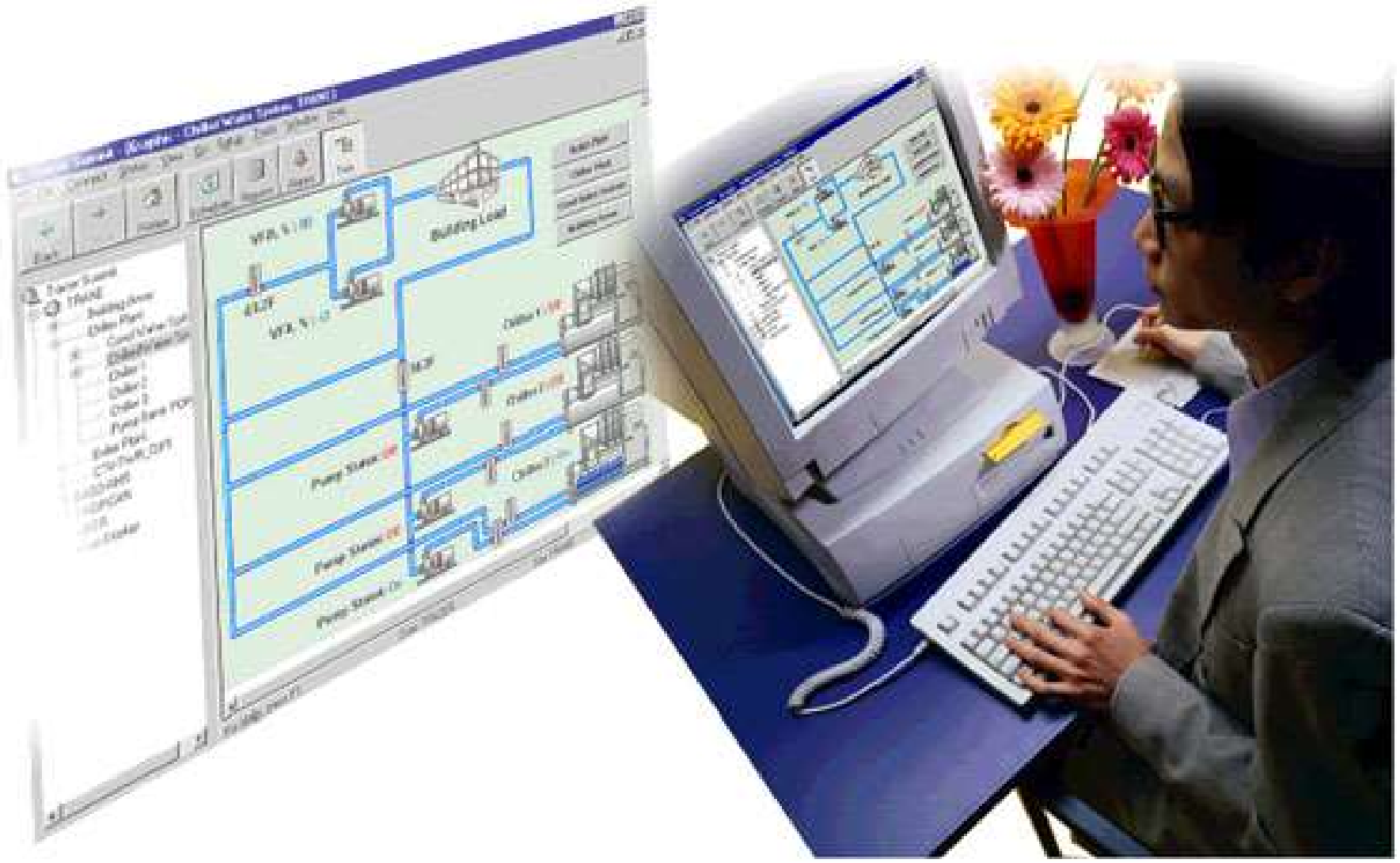
Control of Condensing Pressure



Operator Training and Support



Operator Interface



chiller operating log

ASHRAE Guideline 3

- Chilled-water inlet and outlet temperatures and pressures
- Chilled water flow
- Evaporator-refrigerant temperature and pressures
- Evaporator approach temperature
- Condenser-water inlet and outlet temperatures and pressures
- Condenser water flow
- Condenser-refrigerant temperature and pressures
- Condenser approach temperature
- Compressor-refrigerant suction and discharge temperatures
- Oil pressures, temperature, and levels
- Refrigerant level
- Vibration levels
- Addition of refrigerant or oil

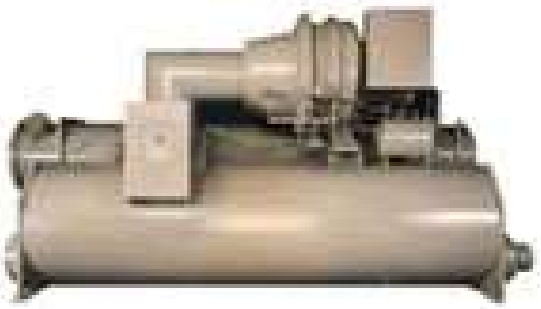
Chilled-Water Systems

period five

Review

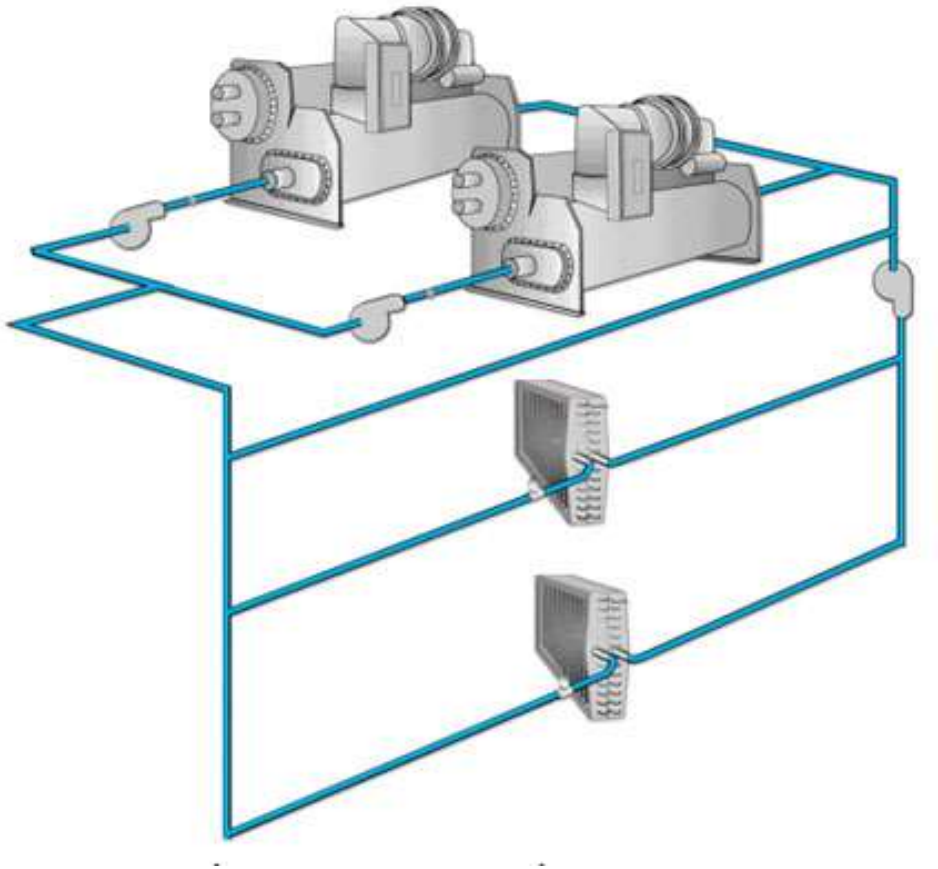
Review—Period One

- **Vapor-compression water chillers**
  - Air-cooled versus water-cooled
- **Absorption water chillers**
- **Equipment rating standards**
- **ASHRAE/IESNA Standard 90.1-1999**



Review—Period Two

- **Load-terminal control**
  - Three-way valve
  - Two-way valve
  - Face-and-bypass dampers
- **Parallel configuration**
- **Series configuration**
- **Primary-secondary configuration**



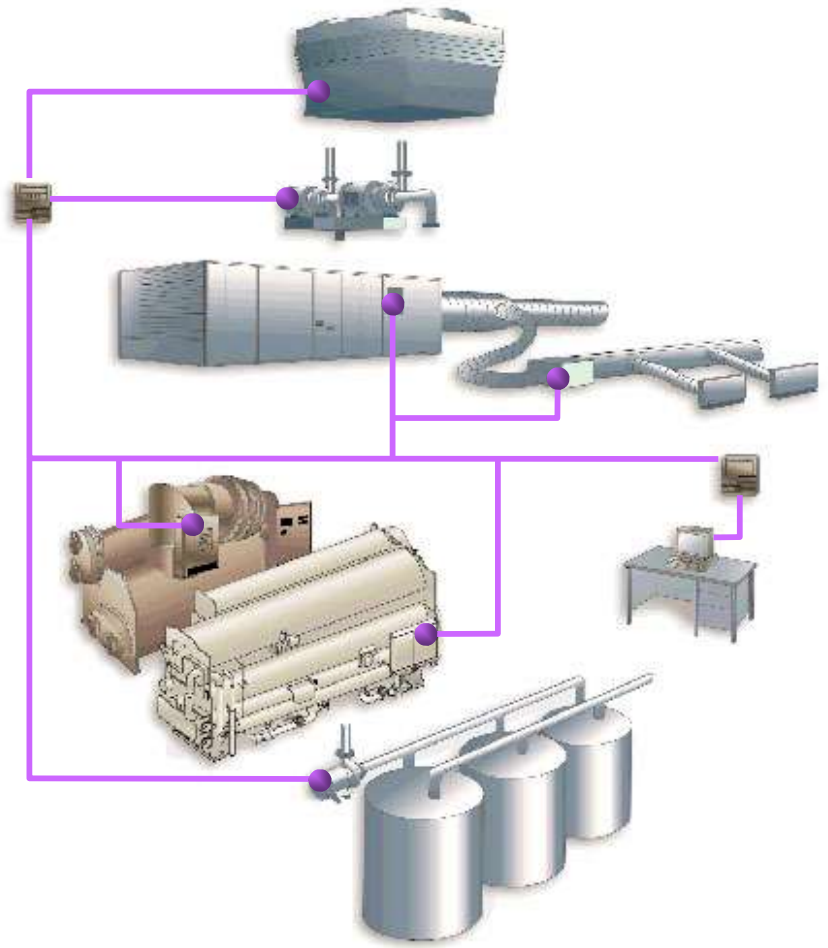
primary-secondary system

Review—Period Three

- Hybrid systems
- Low-flow systems
- Variable-primary-flow systems
- Preferential loading
- Heat recovery
- Asymmetric design
- “Free” (reduced-energy) cooling
- Application of a chiller outside its normal operating range

Review—Period Four

- Chiller sequencing
- Failure recovery
- Contingency planning
- System tuning
- System optimization
- Operator interface



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