Emerging Markets That Are Sure to Last: Indoor Agriculture and Life Sciences

September 2022

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TECHNOLOGIES

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Speaker Introductions

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Thank You to Our Partner Advisory Team Members

- **Chad Salge, P.E.**, Partner
- **Matt Schmidt**, Trane

Indoor Agriculture

What is Indoor Agriculture?

Various Names in Use:

- Controlled environment agriculture (CEA)
- Controlled environment horticulture (CEH)
- Indoor agriculture
- Industrial agriculture
- Plant factories
- Vertical farming
- Urban agriculture

Common Crops:

- Berries
- Cannabis
- Cucumbers
- Hemp
- Herbs
- Lettuce
- Microgreens
- Tomatoes

Why Do People Grow Plants Indoors?

Grower-Controlled Environments:

- Temperature
- Humidity
- Carbon dioxide
- Lighting
- Irrigation
- Fertilization

Predictable, Reliable Products:

- Yield
- Quantity
- Quality
- Grown year-round

Industry Claims

"Some produce has **been on ships and trucks for two weeks** before it reaches the table — having **lost … 45 percent of its nutritional value** along the way." – Plenty
[Plenty, accessed July 6, 2022]

"…allowing us to grow with up to **95% less water**, up to **99% less land**, **zero pesticides** and **a fraction of the fertilizers** compared to field farming." – Aerofarms
[Aerofarms, accessed July 6, 2022]

"…it can get as much as **350 times the produce** out of a given acre of land, **using 1 percent as much water**." – Plenty
[Plenty via Vox, accessed July 6, 2022]

"Each salad **saves up to 10 gallons of water** when compared to field lettuce. We recycle 99.9% of our water.." – Superior Fresh
[Superior Fresh, accessed July 6, 2022]

"…our indoor farms can yield **100 times more produce in the same space** thanks to our vertically stacked design that grows crops year-round." – Bowery
[Bowery, accessed July 6, 2022]

This Isn't Comfort Cooling

Inside the Grow Room

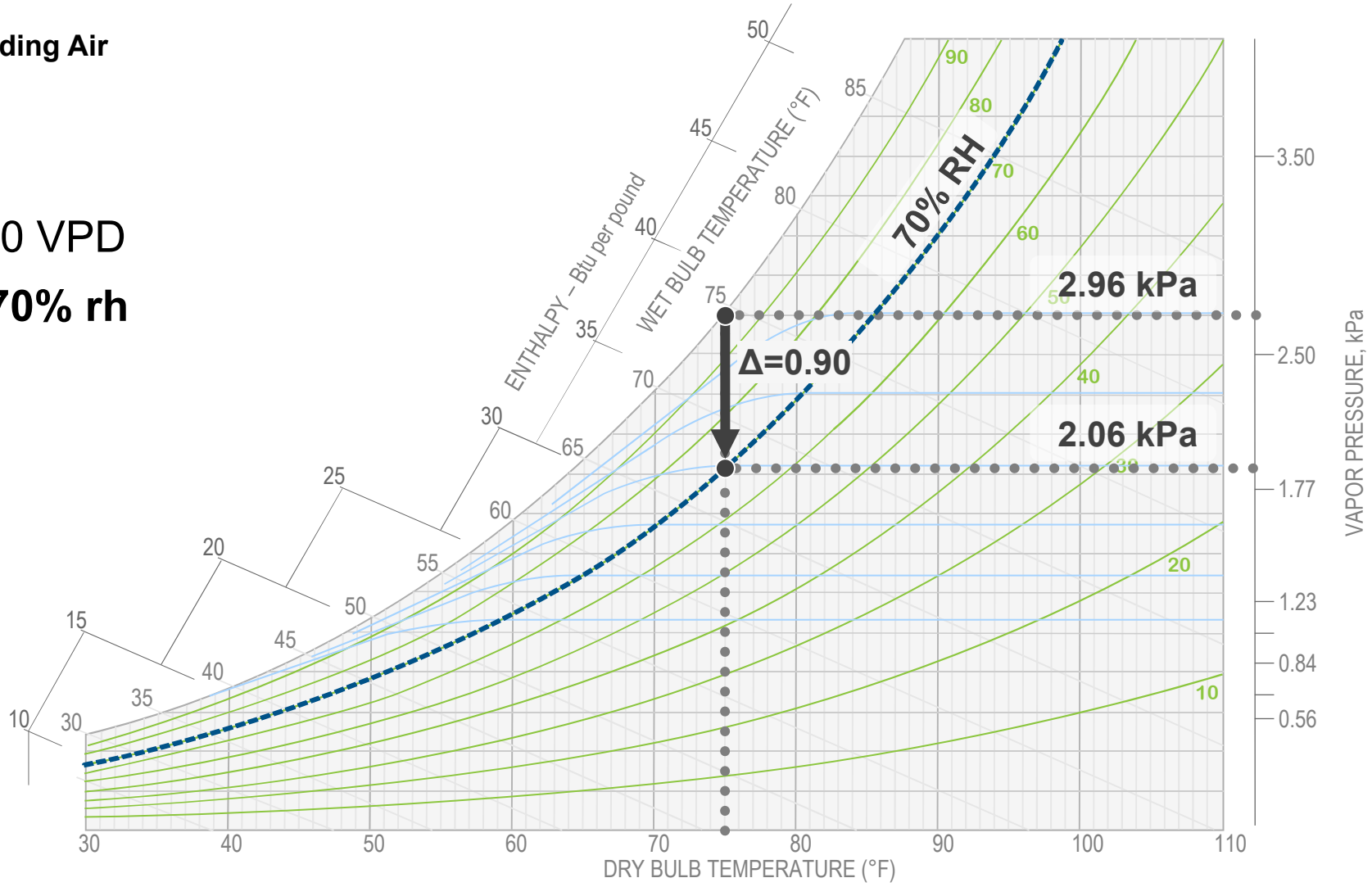
	Comfort Cooling	Indoor Agriculture
Operating modes	Occupied Unoccupied	Lights-on / "Daytime" Lights-off / "Nighttime"
Lighting	0.7 – 1.0 W/ft^2	30 – 80 W/ft^2
Space temperature	70 – 75°F	65 – 83°F
Space humidity	40 – 60% relative humidity	40 – 75% relative humidity
Space SHR	0.70 – 0.90	Daytime: 0.25 – 0.50 Nighttime: 0.00* – 0.40
Ventilation	ASHRAE Standard 62.1 Requirements	Often no ventilation
Carbon dioxide	Diluted with ventilation air (sometimes controlled with DCV)	Increased beyond ambient (e.g., 1200 ppm)

VPD (Vapor Pressure Difference/Deficit)

VPD = VP_{Leaf} – $VP_{Surrounding\ Air}$

Example

- Grower: 75°F DBT, 0.90 VPD
- Setpoints: **75°F DBT**, **70% rh**



LIGHTS ON (“daytime”)

High sensible load from lighting

High latent load from evapotranspiration

\+ Sensible cooling from evaporation

= **Sensible cooling** and **dehumidification**

//RESILIENT TOGETHER//

LIGHTS ON (“daytime”)

High sensible load from lighting

High latent load from evapotranspiration

\+ Sensible cooling from evaporation

= **Sensible cooling** and **dehumidification**

LIGHTS OFF (“nighttime”)

No sensible load from lighting

Medium latent load from evapotranspiration

\+ Medium sensible cooling from evaporation

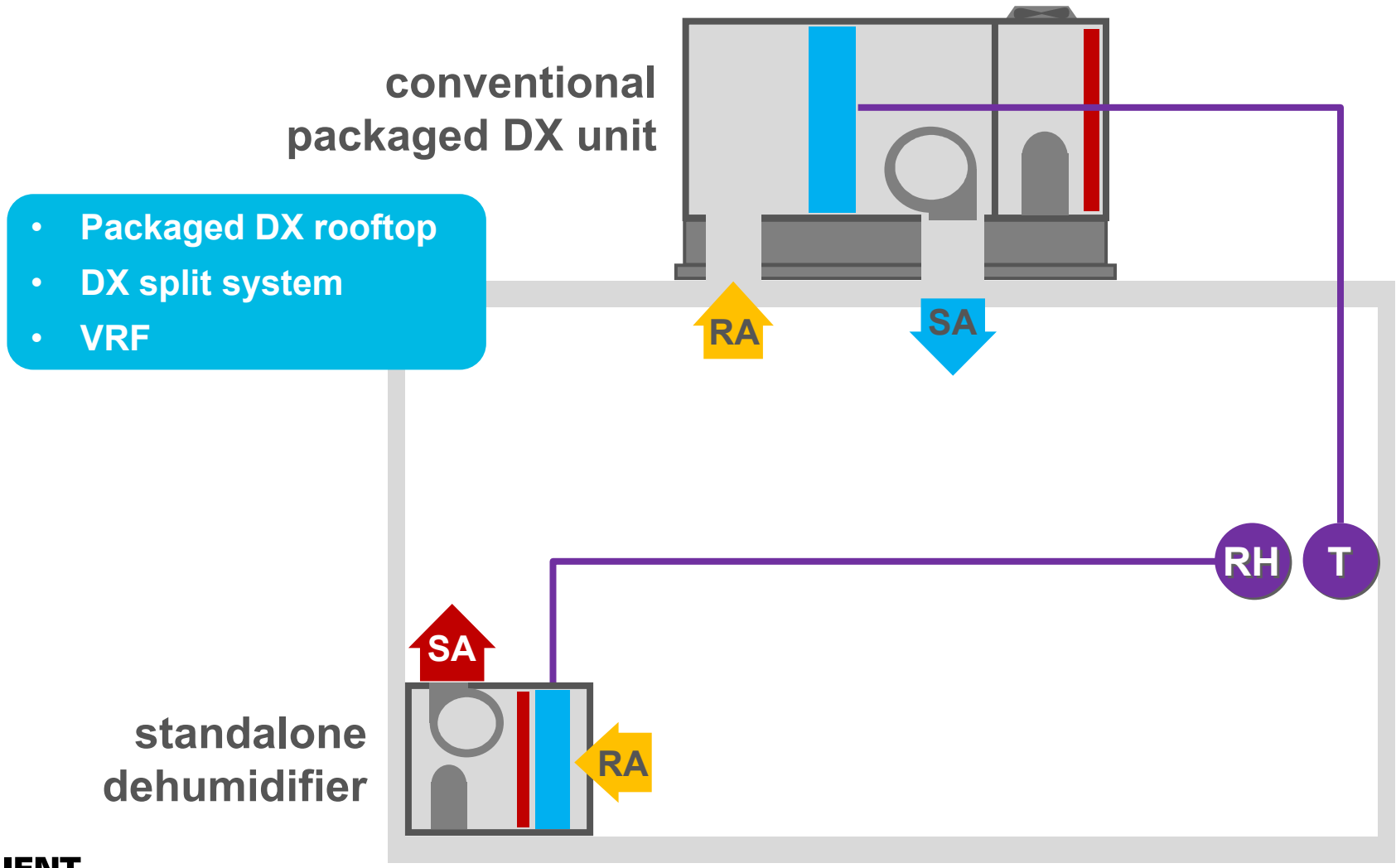
= **Primarily dehumidification**

//RESILIENT TOGETHER//

Indoor Agriculture

Common Airside Systems

Conventional DX units + dehumidifiers



Conventional DX units + dehumidifiers

Advantages

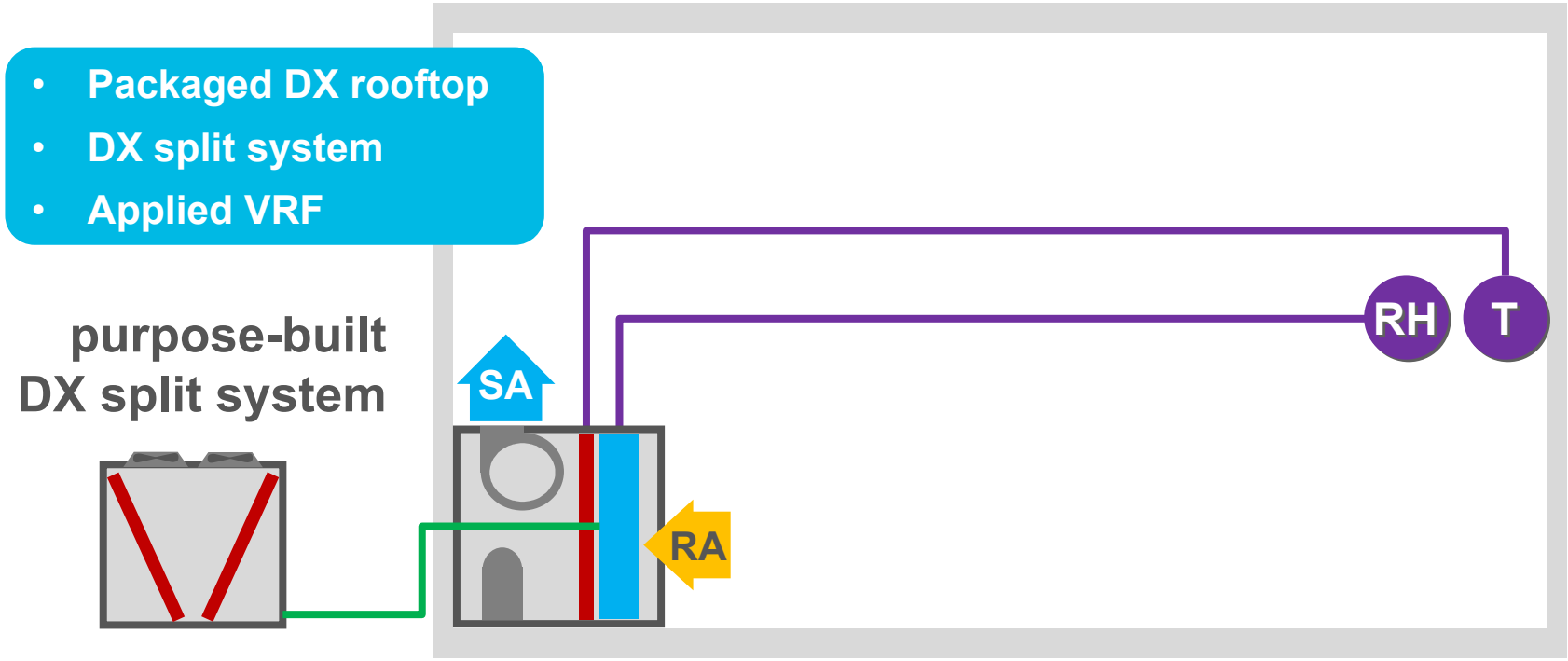
- Fast to install
- Simple controls
- Easy to service
- Likely lowest cost

Drawbacks

- Simple unit control may limit desired operating mode (e.g., dehumidification when OADB less than 40°F)
- Precise space temperature and humidity control can be difficult
- Challenge of operating in cooling mode during cold weather
- Higher energy use compared to other options
- Limited controls integration

Purpose-built packaged or split DX units with reheat

- Packaged DX rooftop
- DX split system
- Applied VRF



Purpose-built packaged or split DX units with reheat

Advantages

- Integrated operating modes (dehumidification, cooling, heating)
- Packaged controls
- Easy to install and service
- More efficient than conventional DX + standalone dehumidifiers

Drawbacks

- Challenge of operating in cooling mode during cold weather
- Higher energy use than some other options
- Higher equipment cost than conventional DX
- Spaces with “negative SHRs” require a supplemental or recovered source of heat

Air-handling units

- Indoor/outdoor AHU
- Chilled water/DX/Applied VRF
- Series (wraparound) air-to-air heat recovery
  - Coil loop
  - Fixed plate HX
- Series desiccant wheel

Air-handling units

Advantages

- Greatest flexibility (heat recovery, construction materials, insulations)
- Range of cooling options (chilled water, DX condensing unit, VRF)
- Integrated operating modes, precise control
- Likely lowest energy use

Drawbacks

- Likely higher installed cost
- May require more skilled service personnel

Indoor Agriculture

Common Chilled Water System Layouts

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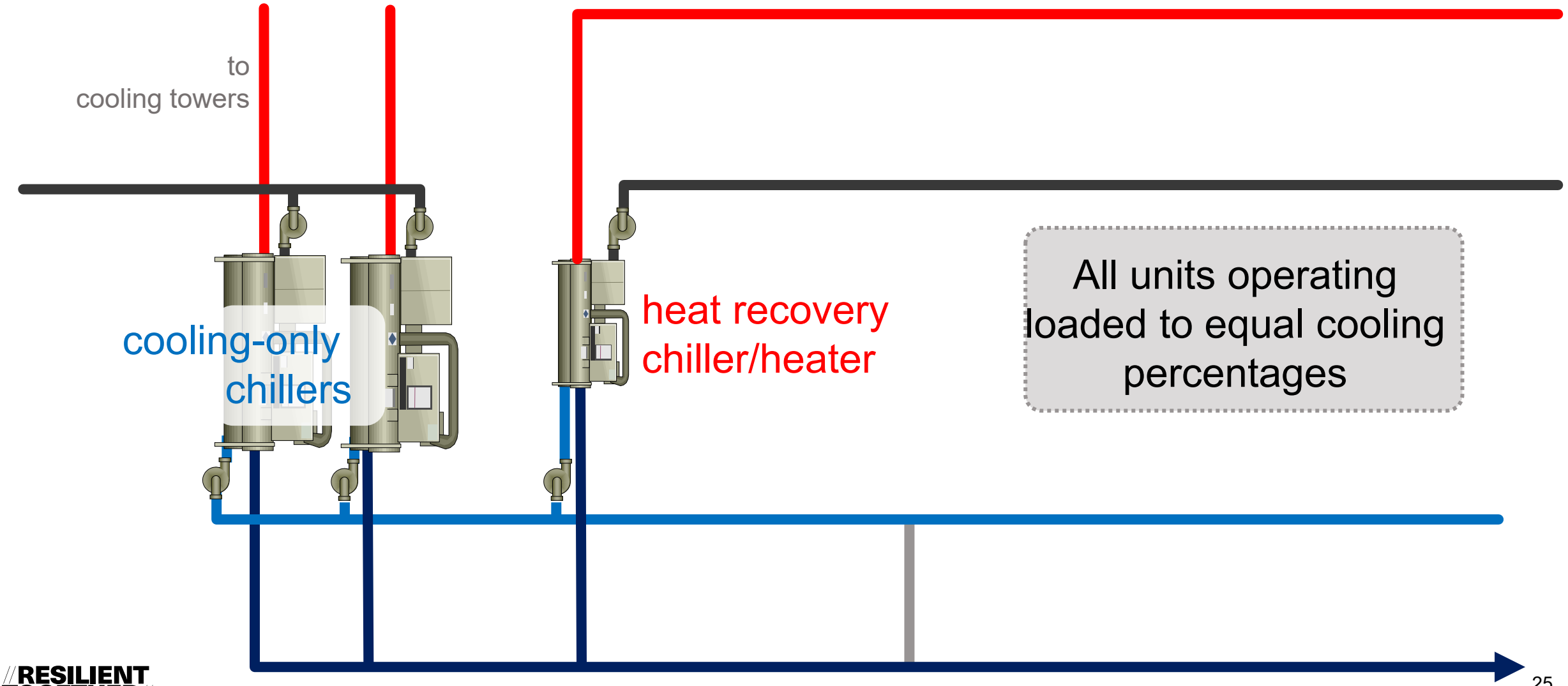
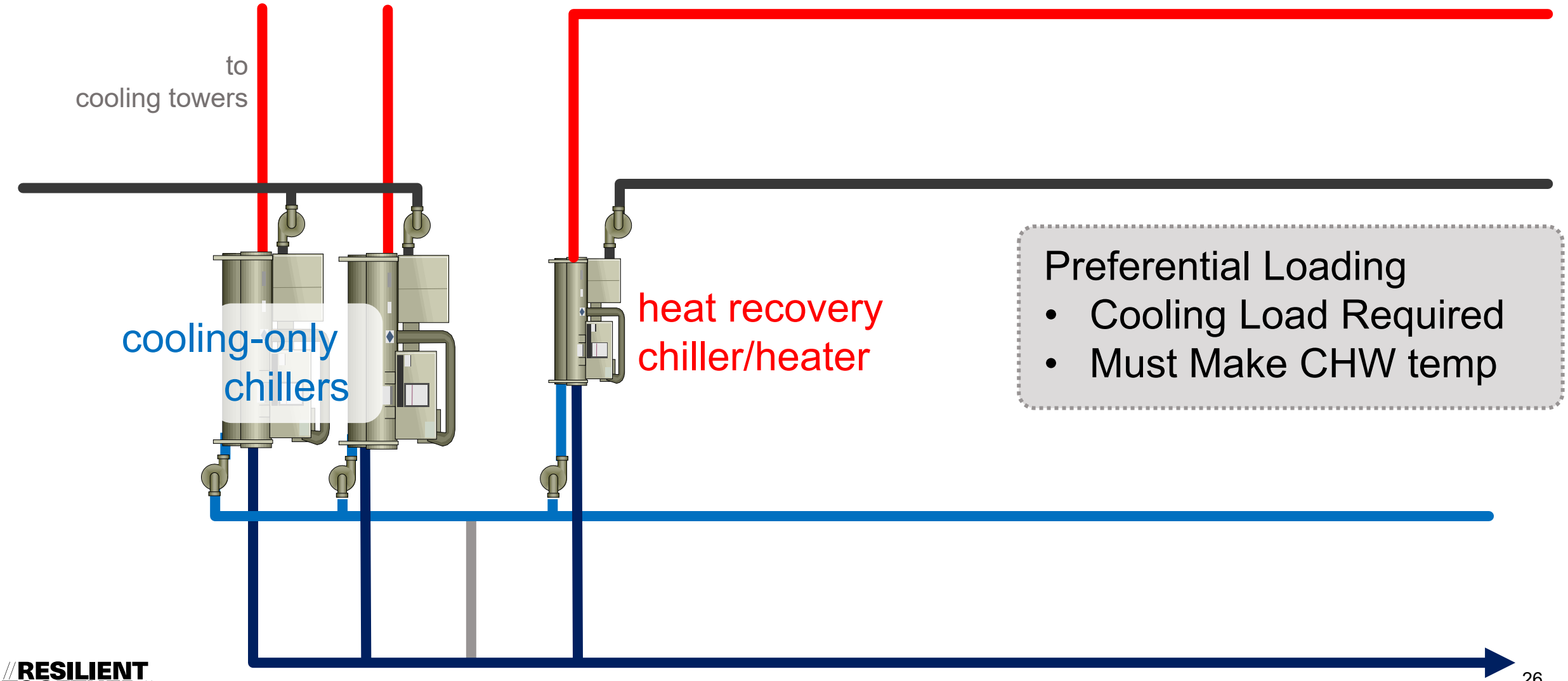
Chilled-Water System Design configurations

- Goals
  - Reliability
  - Simplicity
  - Efficiency
- Plenty of heat to recover
  - Goal, don’t buy additional heat
- System configuration
- Design Considerations
  - Day/Night Loads for sizing
  - Heat recovery
  - Air- or water-cooled chillers
  - Waterside economizer
- Alternate piping/distribution configurations

Parallel Heat Recovery Chiller

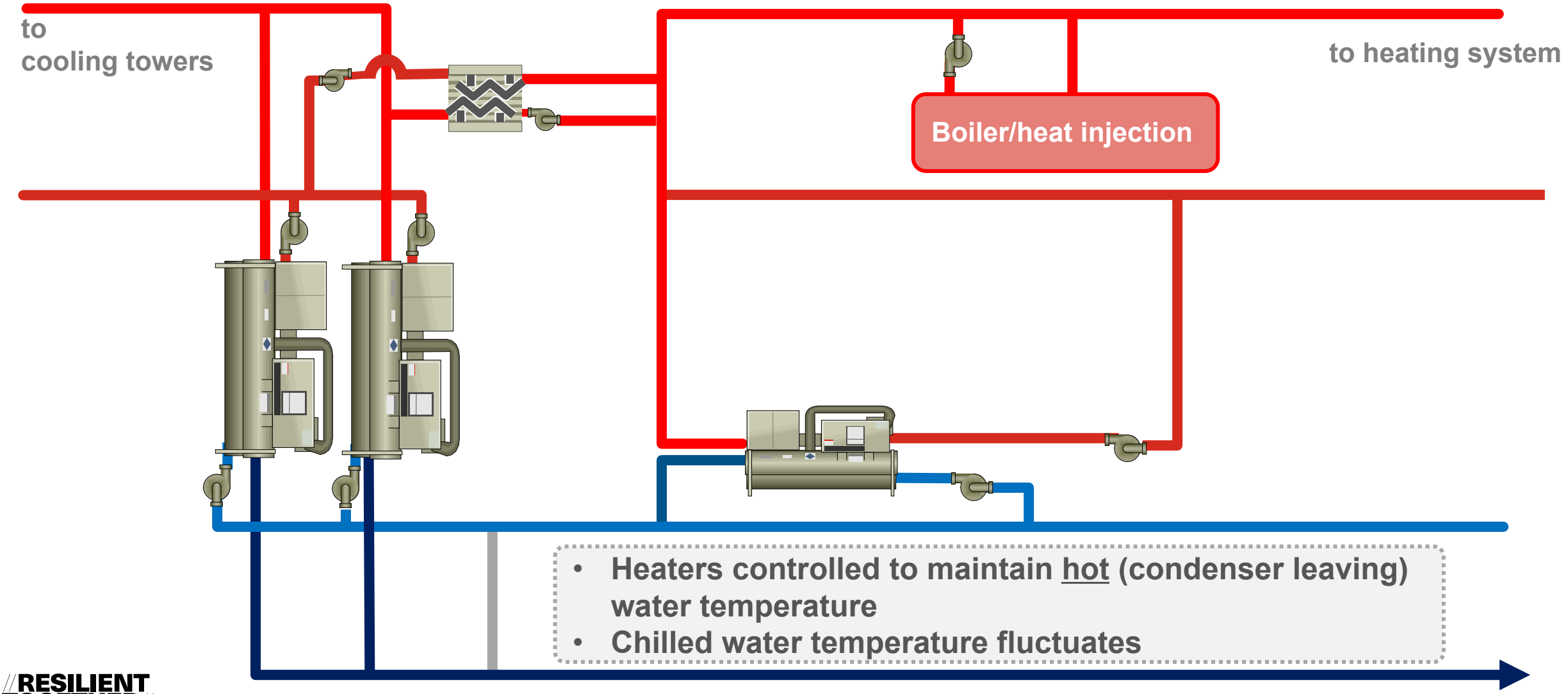


Parallel Heat Recovery Chiller/Preferential Loading



Preferential Loading
- Cooling Load Required
- Must Make CHW temp

“Heaters” in sidestream position



What Do Indoor Agricultural Customers Want?

- Reliability
- Up-time
- Fast Service

Trane Solutions

Trane-Branded Split Systems
- 5 – 30 tons
- Hot gas reheat

MSP Air Handlers
- 1,000 – 12,000 cfm
- Series fixed plate air-to-air heat exchanger

Trane Chillers
- 20 – 4,000+ tons
- Heat recovery, heat pump, Free cooling
- Modular models

Horizon Thrive
- 3 – 80 tons
- Hot gas reheat

Trane Climate Changer Air Handlers
- 1,000 – 200,000+ cfm
- Air-to-air energy recovery, CDQ

VRF
- Linear expansion valve (LEV) kit
- Up to 20 tons per LEV kit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Compare and Contrast

Laboratories

A room or building equipped for **scientific experiments**, **research**, or **teaching**, or for the manufacture of drugs or chemicals.

- Controlled environment
- Often 100% outdoor air
- Negative or positive pressurization

Cleanrooms

An environment **free from dust** and **other contaminants**, used chiefly for manufacturing.

- Controlled environment
- Many recirculated air changes per hour
- Often positively pressurized
- Contaminant sources:
  - Indoor and outdoor sources
  - Airborne, surface-borne particulates
  - Airborne molecular contaminants (gases, vapors, chemicals, etc.)
  - Liquid-borne contaminants (acids, bases, solvents, ultrapure water)
  - Microbial contaminants

Lab Biosafety Levels and Biological Safety Cabinets

Biosafety Levels (BSL)

- Class 1 to 4
- Increasing hazard risks
  - Minimal to lethal
- Higher PPE levels
  - None to positive pressure suits
- Increasing access stringency
- Cleanability/isolation
- Filtration/exhaust requirements
- Safety officers perform hazard studies

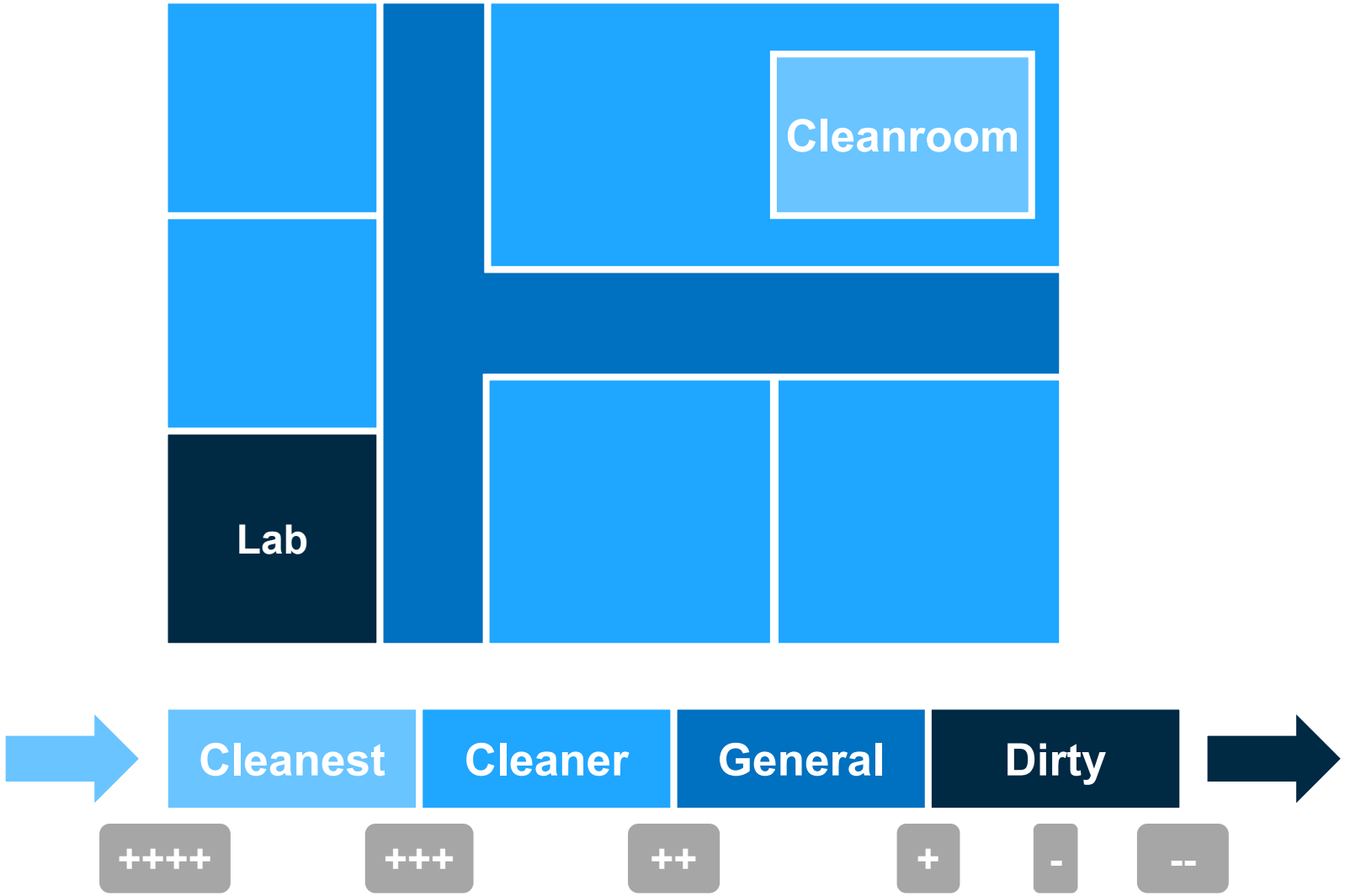
Biological Safety Cabinets (BSC)

- Class I to III, Type A1 to B2
- Increasing hazard risks
  - Volatility, flammability, toxicity, radioactivity
- Protects personnel, environment, research material
- May recirculate in cabinet or 100% exhaust
- Isolated exhaust may be required
- Isolation/decontamination dampers
- HEPA/incineration prior to discharge


Laboratories

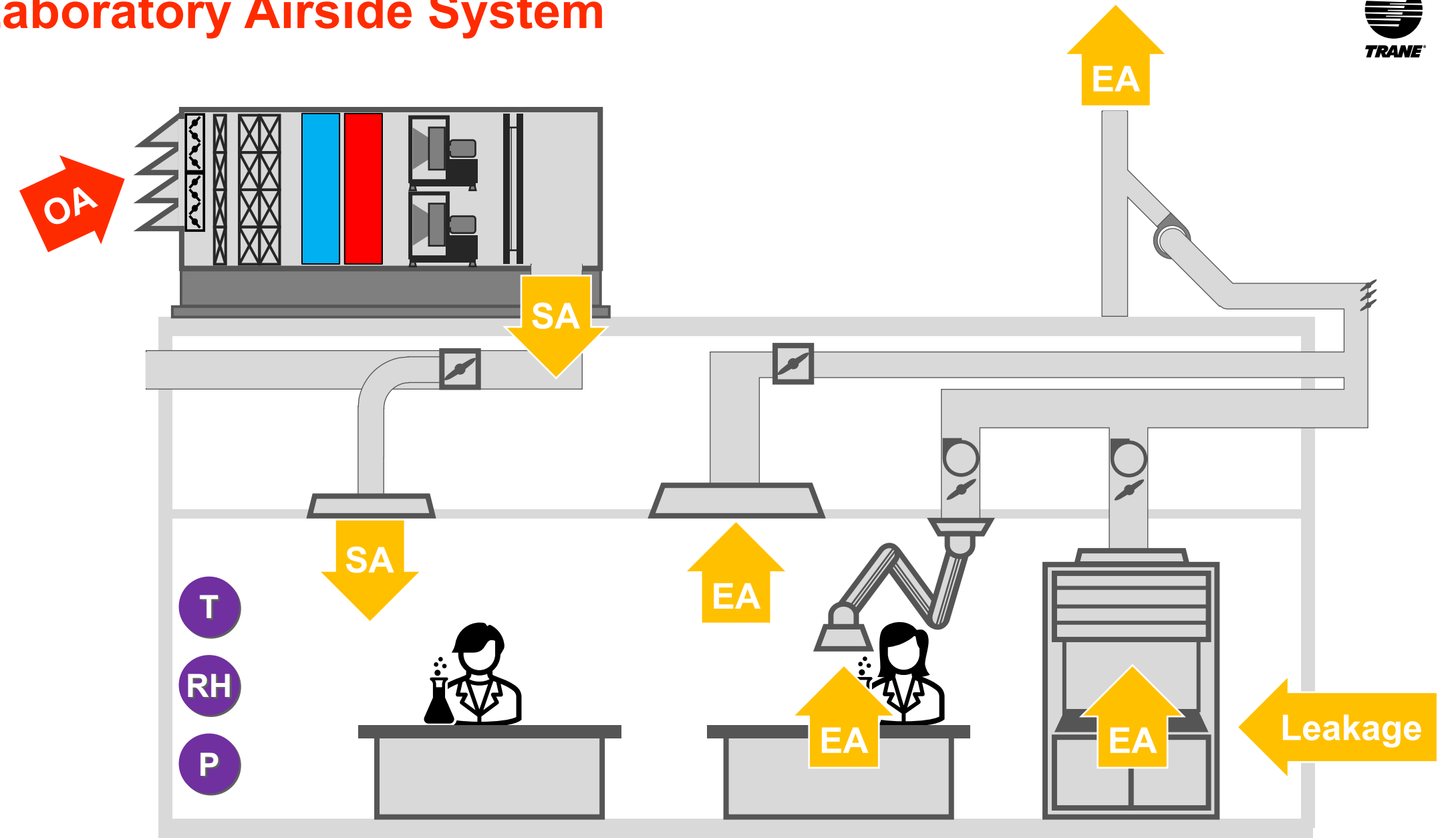
Pressure Mapping

Directional Zone-to-Zone Flow Control



0.01 to 0.05 in. H_2O pressure differential between zones

Typical Laboratory Airside System



Typical Laboratory Airside System

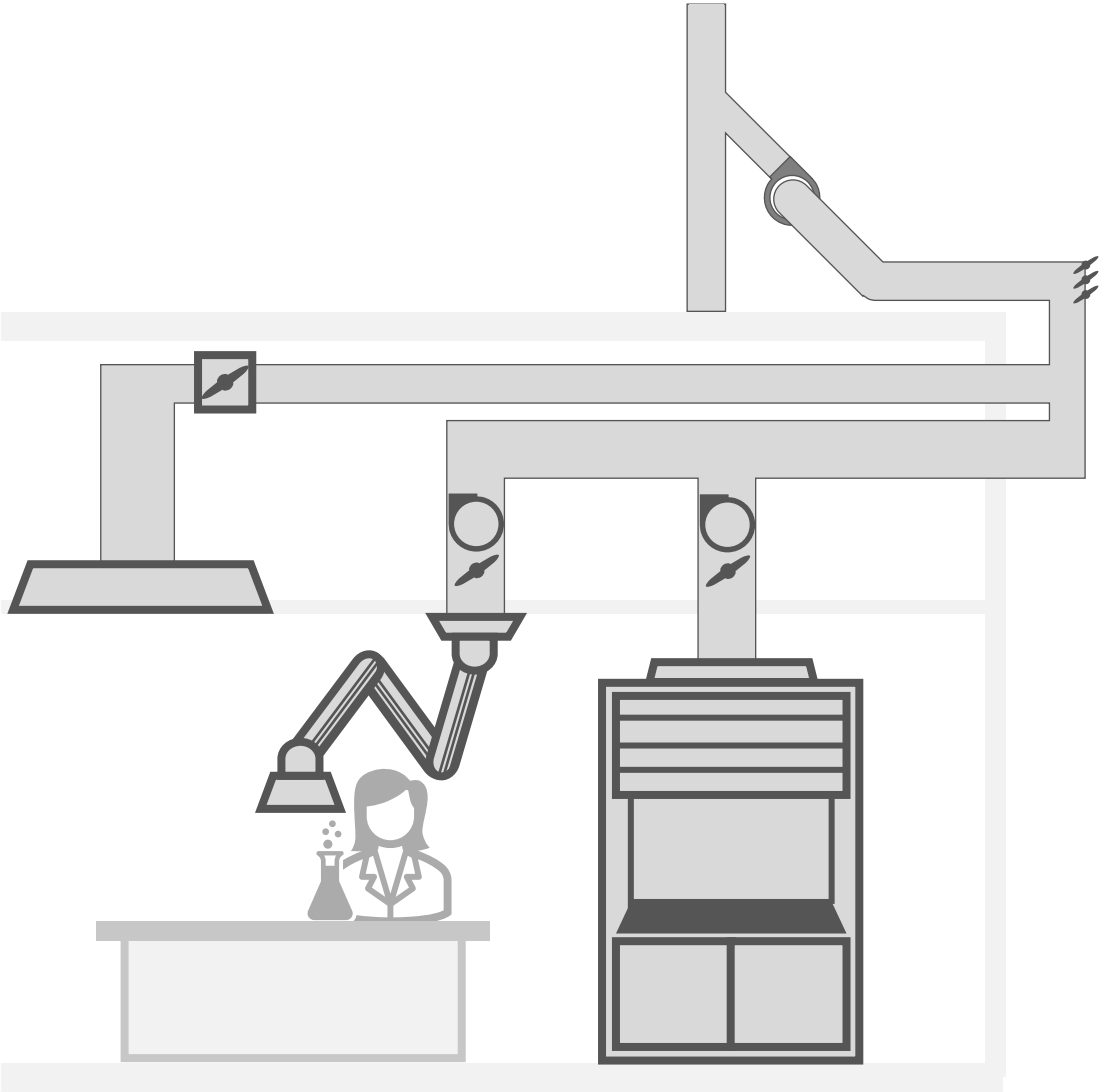
Exhaust System

Exhaust Systems

- Designed first
- Multiple exhaust components
  - General exhaust: variable volume
  - Snorkels: often variable volume
  - Hoods: movable sash, often variable volume
- Air-to-air energy recovery
- Special considerations for chemicals and particulates
  - Filtration, gas phase air cleaning
- Unique exhaust stack design
  - Design to prevent re-entrainment with plume height and velocity

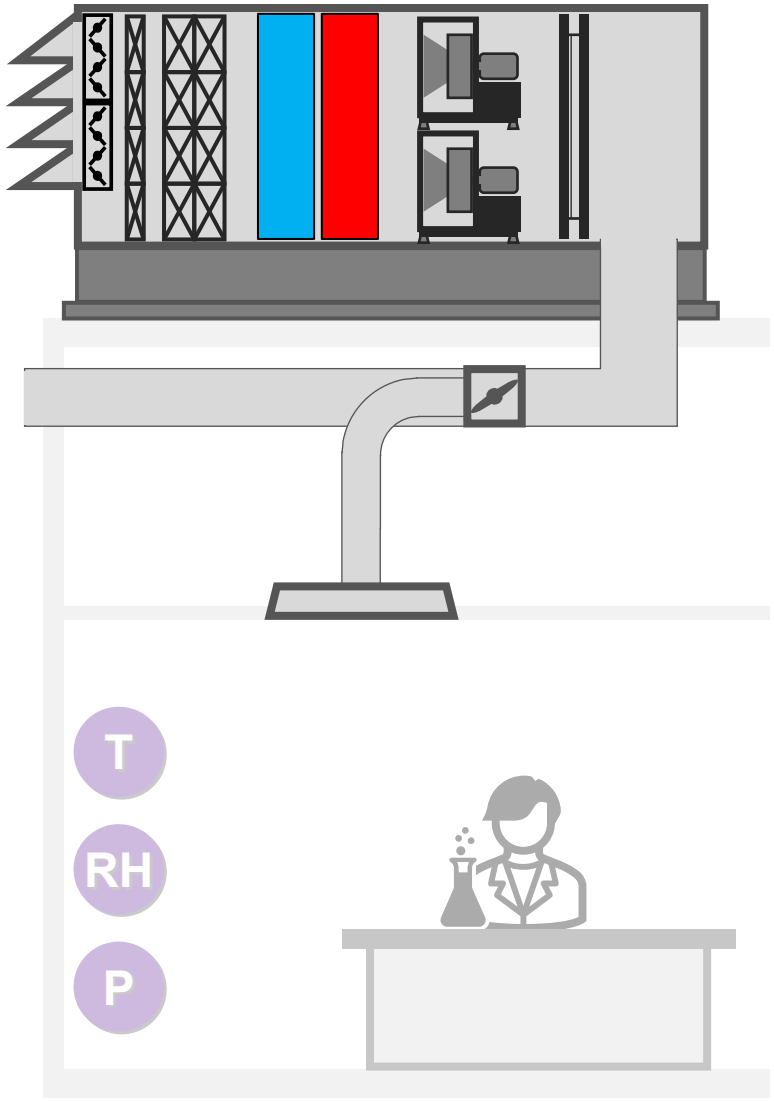
Exhaust Rates

- Exhaust airflow rates often exceed required conditioning airflow rate



Typical Laboratory Airside System

Supply Air System



Supply Air System(s)

- Centralized or dedicated air systems
- High ACH rates, low velocity discharge
  - General: 6 – 10 ACH
  - Animal Rooms: 10 – 15 ACH
- Often 100% outdoor air
  - Cooling, heating, dehumidification, humidification
- Air-to-air energy recovery
- Filtration (pre-, post-filtration)
  - MERV 7 – 8 to MERV 13 – 16
  - HEPA/ULPA

Supply Air Rates

- Maintain required air change rates (large volumes of supply air)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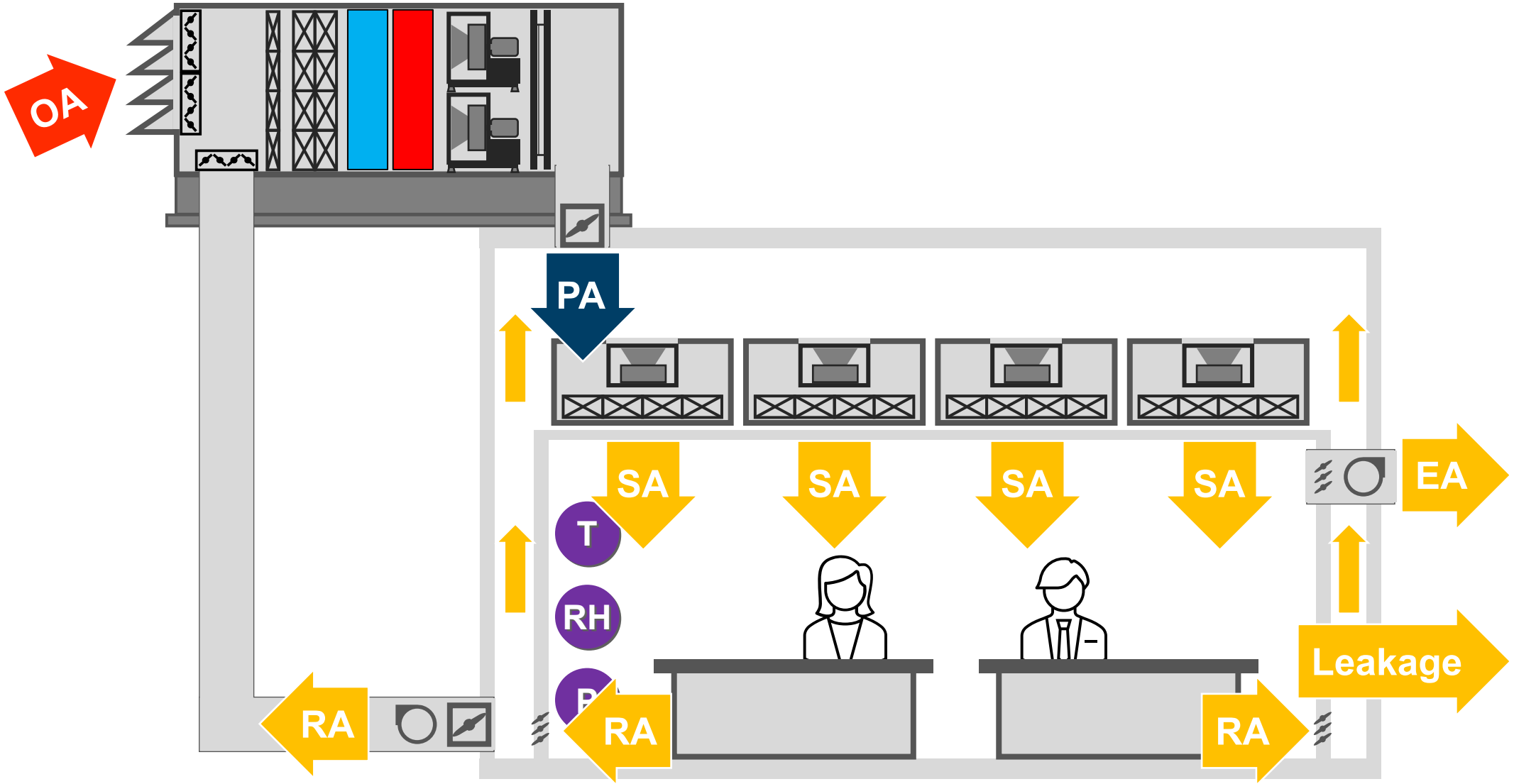
Typical Cleanroom Airside System (Single AHU with Filter Fan Units)



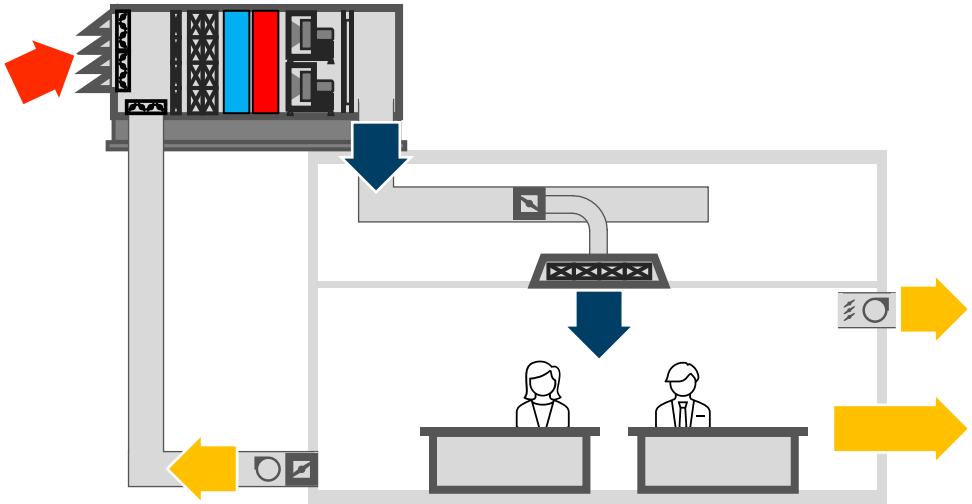
Cleanroom Classifications and Typical Applications

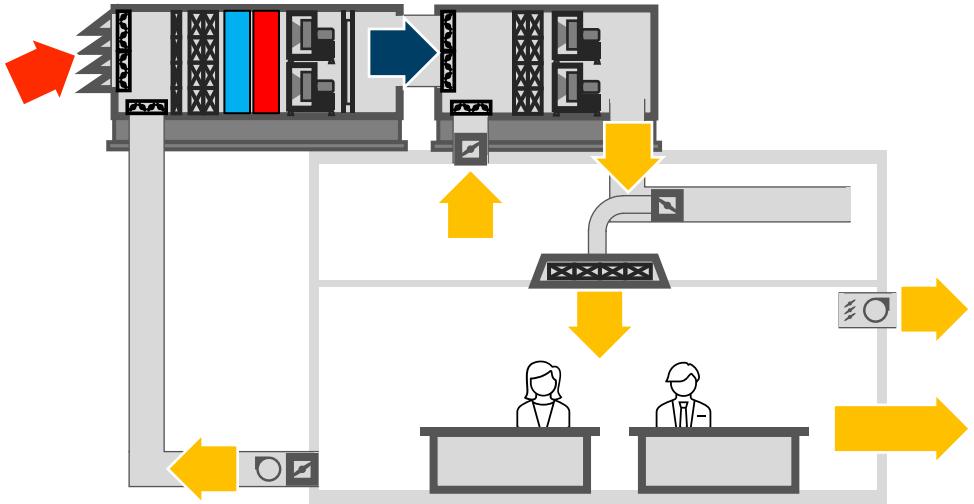
Classification		Maximum Number of Particles in the Air (particles/m^3)						Typical ACH Rates[1]	Typical FFU Ceiling Coverage[2]	Typical Applications
ISO 14644-1	FS 209D Equivalent	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm			
Class 1		10	2					360 – 600	80 – 100% ULPA	Nanotechnology Semiconductors
Class 2		100	24	10	4			360 – 600	80 – 100% ULPA/HEPA	
Class 3	**Class 1**	1,000	237	102	35	8		360 – 540	60 – 100% ULPA/HEPA	
Class 4	**Class 10**	10,000	2,370	1,020	352	83		300 – 540	50 – 90%	
Class 5	**Class 100**	100,000	23,700	10,200	3520	832	29	240 – 480	35 – 70%	Biotechnology Pharmaceutical Semiconductors
Class 6	**Class 1,000**	1,000,000	237,000	102,000	34,200	8,320	293	150 – 240	25 – 40%	Automotive EV batteries
Class 7	**Class 10,000**				352,000	83,200	2,930	60 – 90	15 – 25%	Packaging
Class 8	**Class 100,000**				3,520,000	832,000	29,300	5 – 48	5 – 15%	Gowning
Class 9	**(Room Air)**				3.5×10^7	8,320,000	293,000	4 – 25		

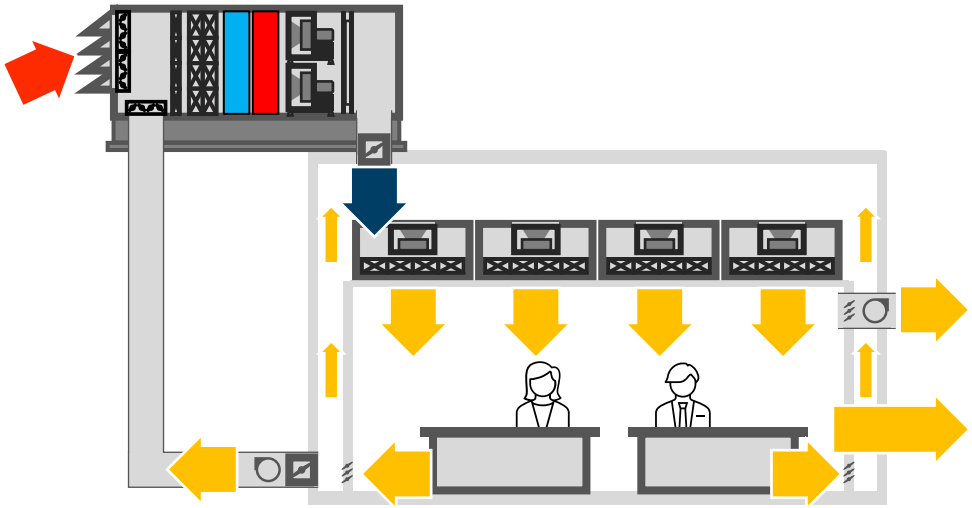
1: source – IEST RP12.1
2: source – Clean Air Products

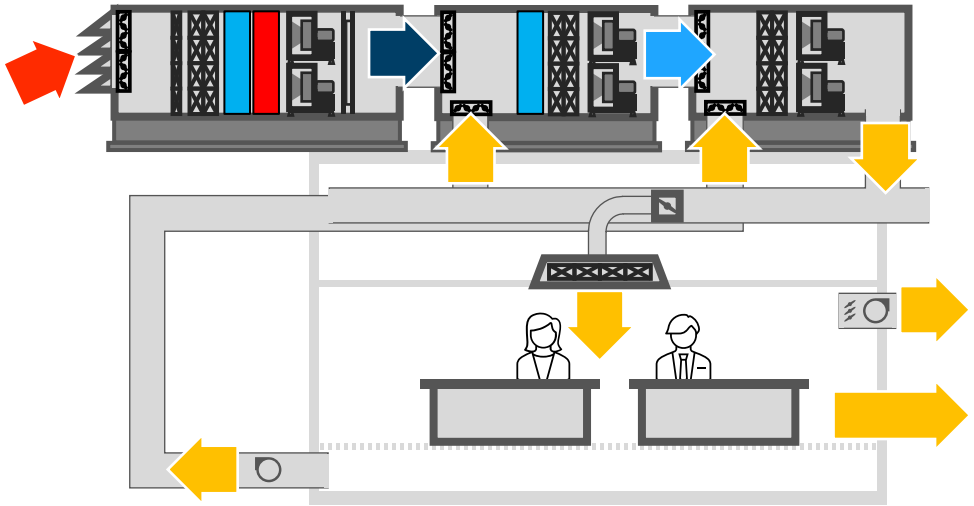
Cleanroom Airside Systems

Numerous Configurations









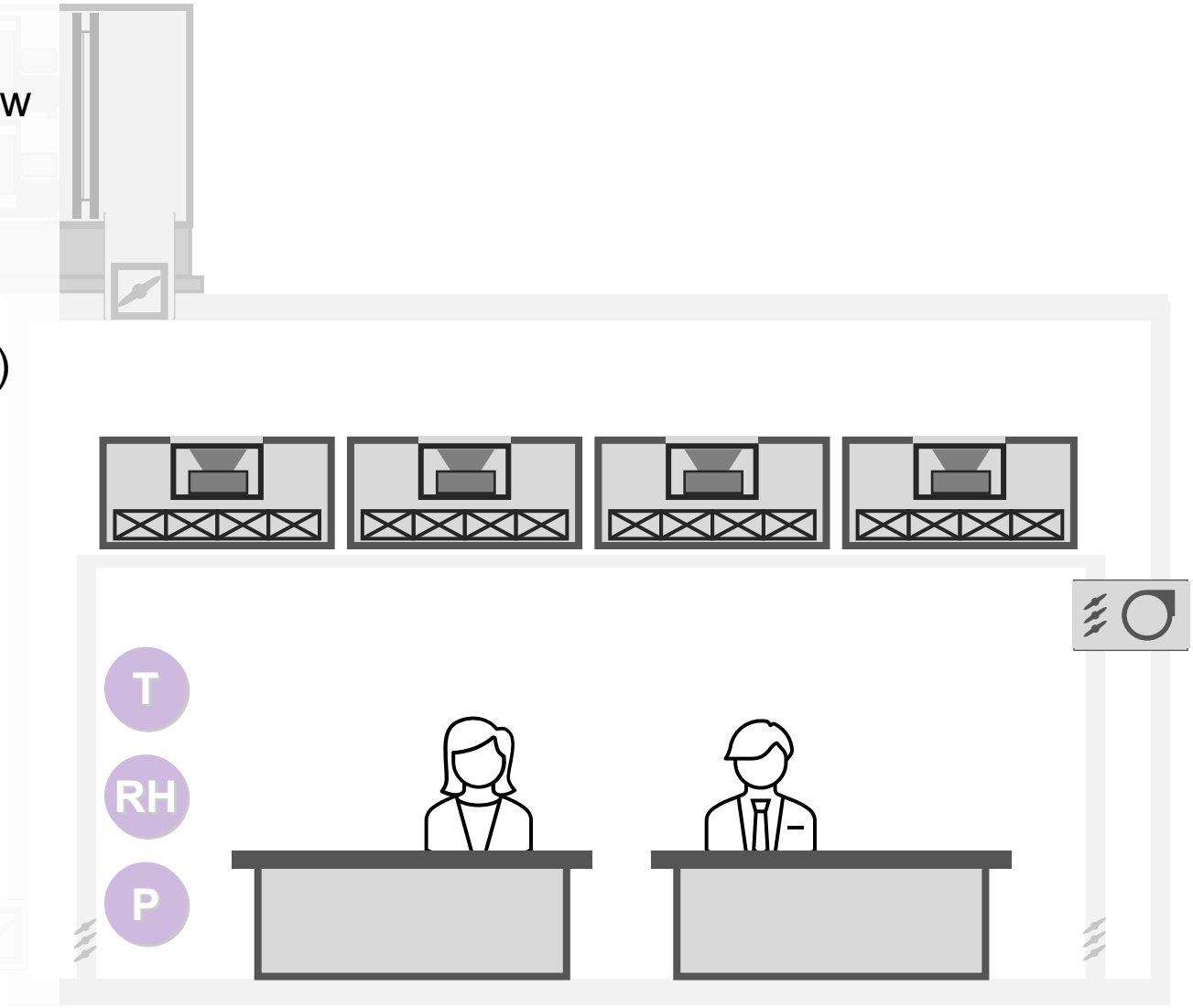
Typical Cleanroom Airside System
Cleanrooms

Cleanrooms

- ISO class 5 and higher: Unidirectional airflow (vertical, sometimes horizontal)
- ISO class 6 – 8: nonunidirectional airflow
- Raised floor- and/or wall-mounted returns
- Multiple ISO classes (occupied/unoccupied)

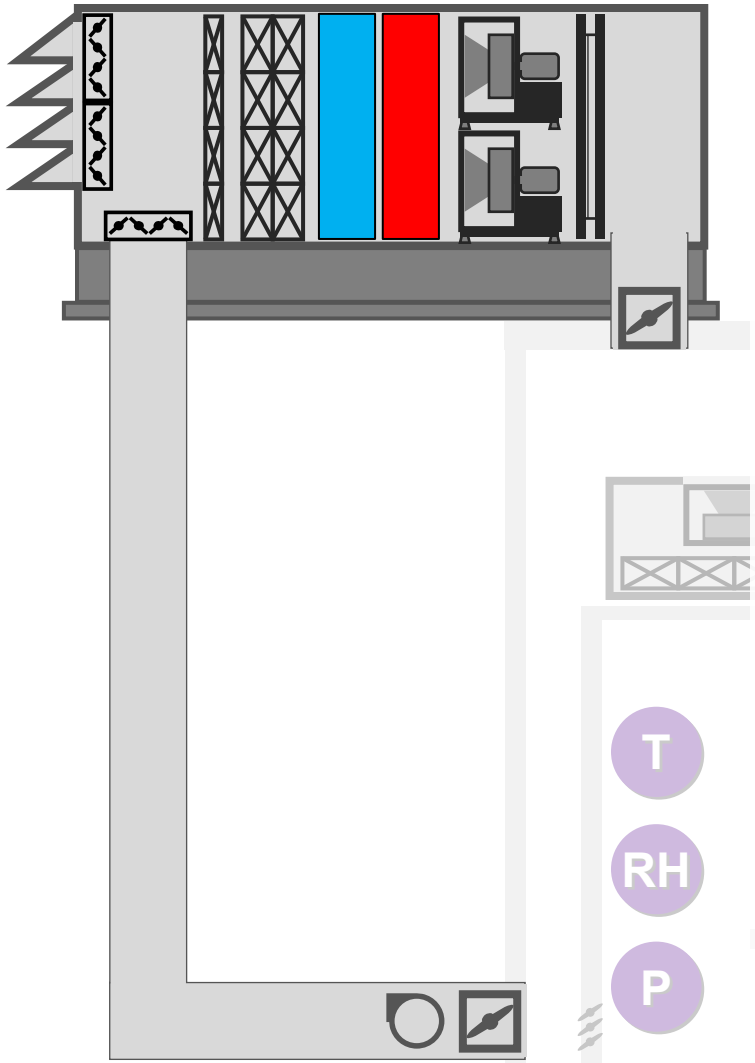
Fan Filter Units (FFUs)

- Designed for modular ceiling grid systems
- Provides cleanroom ceiling coverage
- Produce unidirectional (laminar) flow
- HEPA/ULPA filtration
- Satisfy ACH and velocity requirements



Typical Cleanroom Airside System

Air Handling System(s)



Supply Air Systems

- Provide OA: replace process exhaust, worker ventilation, pressurization requirements
- Pre-filters, filters, HEPA filtration
- Numerous configurations:
  - Single AHU
  - Primary Recirculation Unit with Secondary AHU
  - Primary Filter Fan Units (FFUs) with Secondary AHU
  - Primary Recirculation Unit + Secondary AHU + Tertiary MAU

This Isn't Comfort Cooling

Inside the Laboratory or Cleanroom

	Comfort Cooling	Laboratories	Cleanrooms
Supply air	~4 – 10 ACH	High air change rates • General: 6 – 10 ACH • Animal Rooms: 10 – 15 ACH Velocity limits (~50 fpm/50% hood face velocity)	High air change rates • Cleanrooms: 20 – 600+ ACH Velocity limits
Ventilation	Standard 62.1	Often 100% Outdoor Air	Ventilation and recirculated air
Exhaust	Dictated by ventilation and economizing	One or more exhaust systems (general exhaust, room exhaust: hoods, snorkels)	One or more exhaust systems (general exhaust, room exhaust)
Air cleaning	Supply filtration • MERV 8 – 13	• Supply and exhaust (pre-, post-filtration) • MERV 8 – 16, HEPA, gas-phase	• Supply, possibly exhaust • Fan filter units (FFUs) • MERV 8 – 16, HEPA, ULPA
Space temperature	70 – 75°F	Process-dictated • Possible tight tolerances	Process-dictated, tight tolerances • Li-ion manufacture: ~70°F • Semiconductors: 65 – 74°F ± 0.1°F
Space humidity	40 – 60% relative humidity	Process-dictated • Latent-producing equipment may be independently-vented	Process-dictated • Li-ion manufacture: ~2 – 10% RH • Semiconductors: 30 – 50% ± 0.5%
Pressurization	Passively or actively controlled	Actively controlled: often negative (Prevent exfiltration)	Actively controlled: positive (Prevent infiltration)

Laboratories and Cleanrooms

Common Hydronic Systems

Waterside Considerations

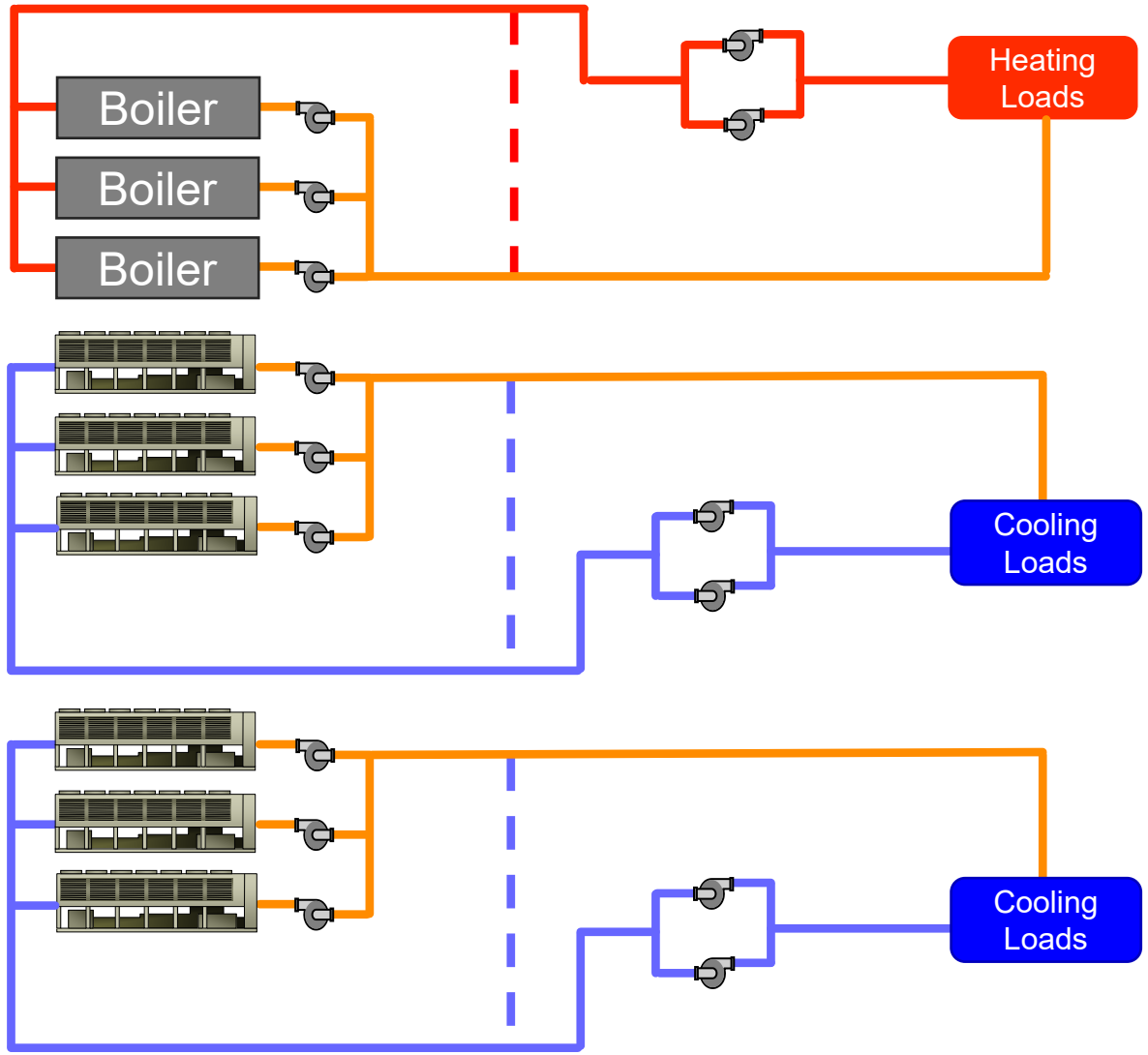
- Multiple Temperatures Required
  - Dehumidification of OA with ‘cold fluid’ 39 – 42°F
  - Sensible cooling with ‘medium temperature fluid’ 55 – 65°F
  - Process Loads

- Single or Multiple Plants
  - Redundancy
  - Efficiency
  - Complexity
  - First Cost
  - Operational Cost
- Heat Recovery

Dual Temperature Plant - Typical Layout

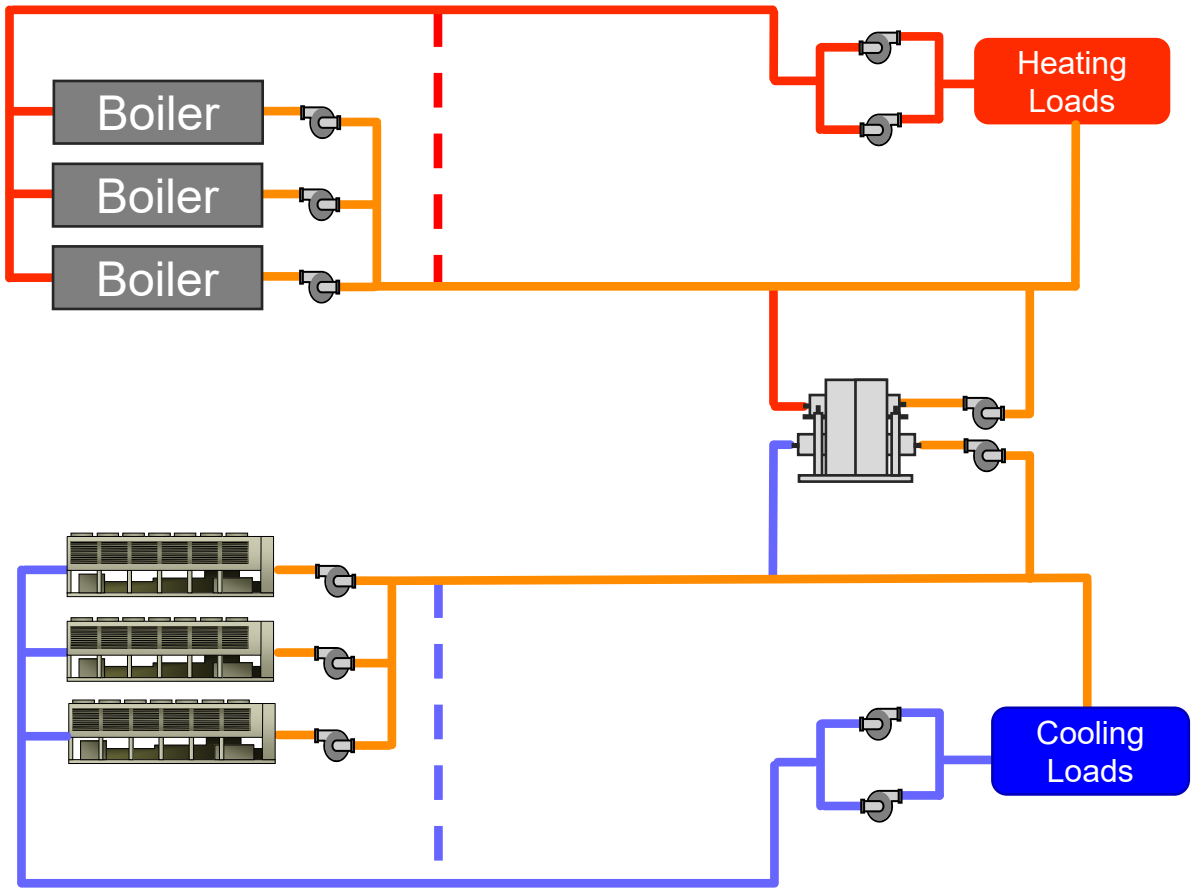
- Boilers serve hot water loads
  - Space conditioning
  - Reheat
  - Water heating
  - Process Loads

- Multiple chiller plants
  - Low temperature
  - Medium temperature
  - Space conditioning
  - Process Loads



Heat Recovery Chiller - Sidestream

- Use heat rather than rejecting
- Improves overall efficiency
- Control
  - Evaporator
  - Condenser
- Size to meet the load
- Primary pumps ↑
- Primary pipes ↑

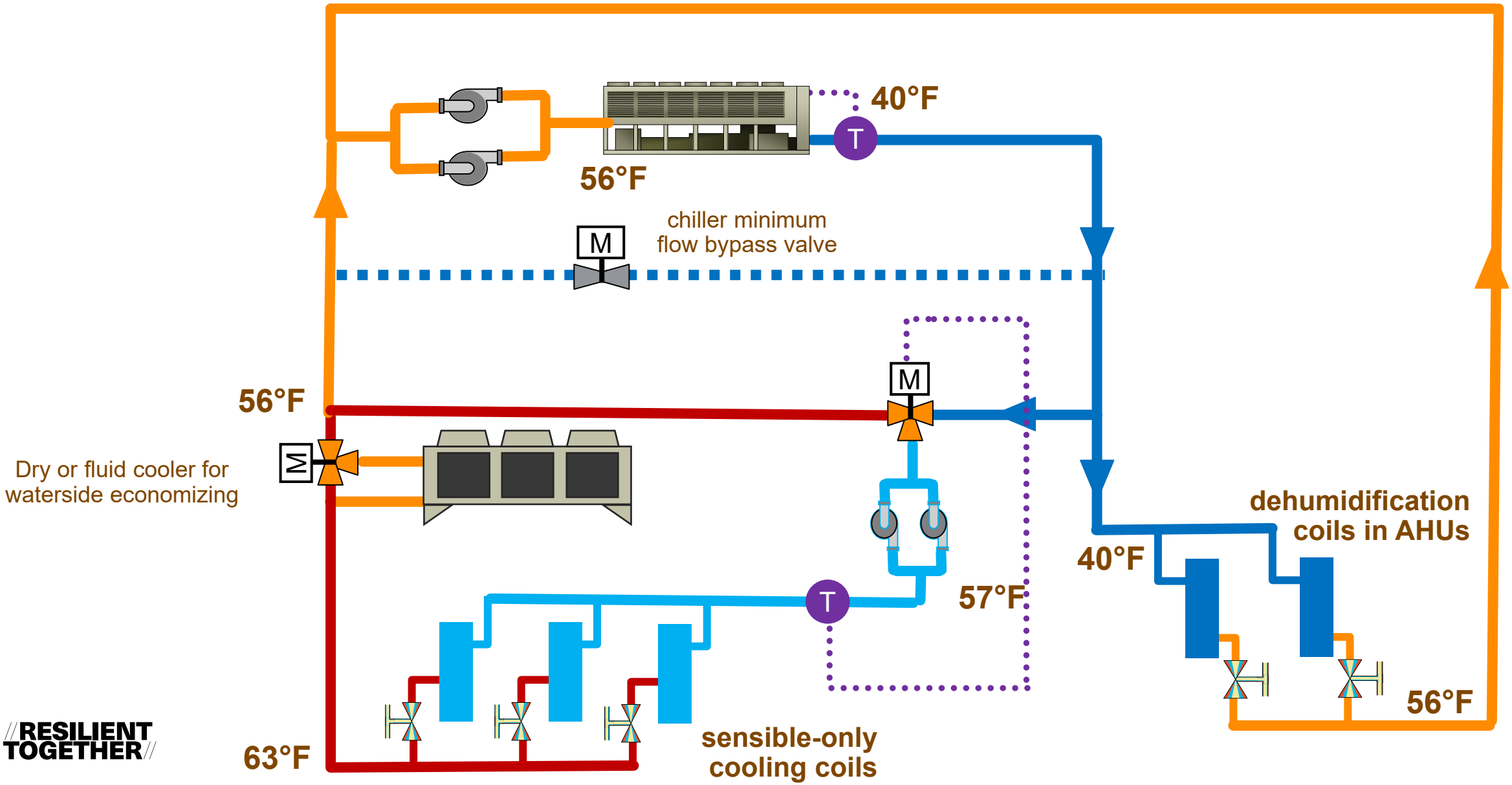


Dual-Temperature Plants

- Dehumidify fresh air coming in
- Further condition air in the spaces for better control
- Heat exchanger locations
- Isolated loops
- Series/Parallel load configuration

Typical Waterside Configuration

Dual Temperature Plant with Blending Valve

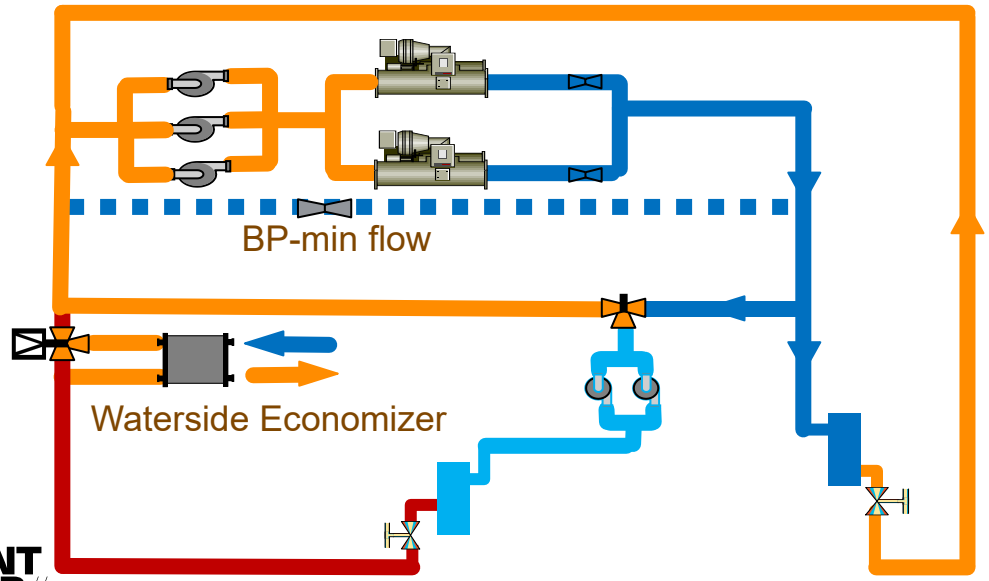


Typical Waterside Configuration

Two-chiller plant (parallel loads)

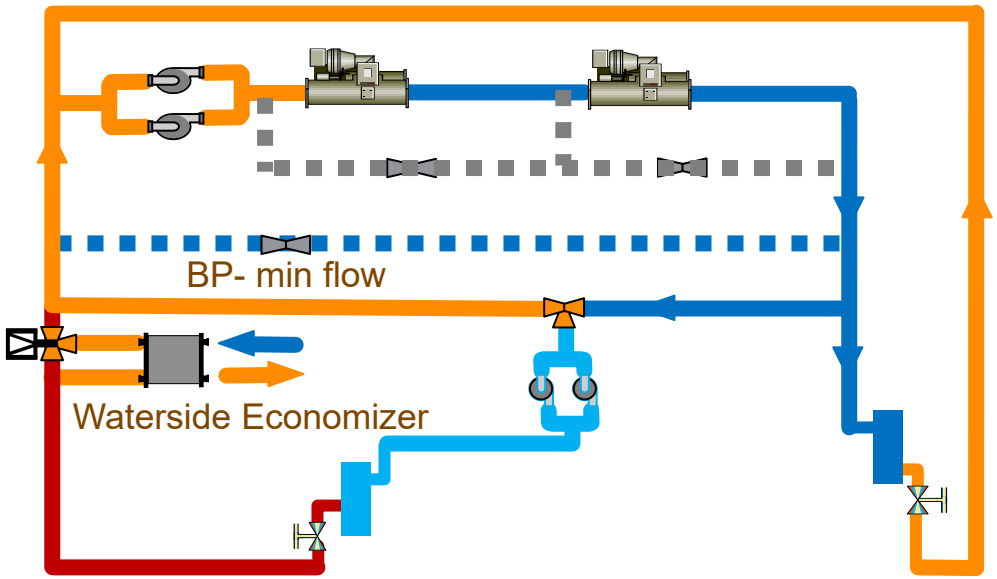
Parallel Chillers

- Redundancy
  - Size each for 60-70% of full load
- Blend or isolation HX



Series Chillers

- Wide Delta T
- Less lift per chiller -> efficiency gains
- Pump power penalty
- Free cooling upstream



Typical Waterside Configuration

Two-chiller plant (series loads)

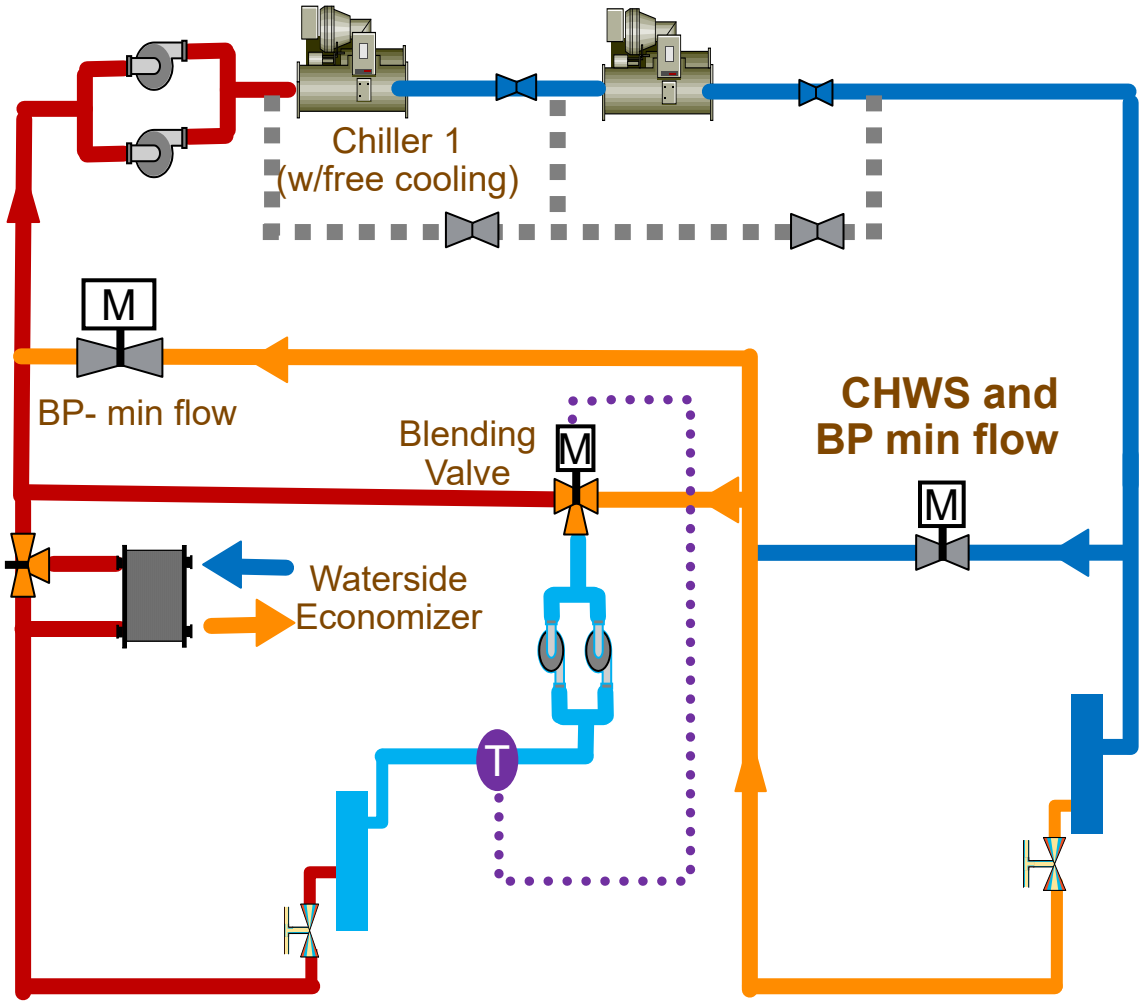
Other Options

- Series Loads
  - Upstream chiller
    - Selected for warmer water
    - Dual purpose bypass valve

↓ Overall plant flow

↑ Complex control

↓ Redundancy

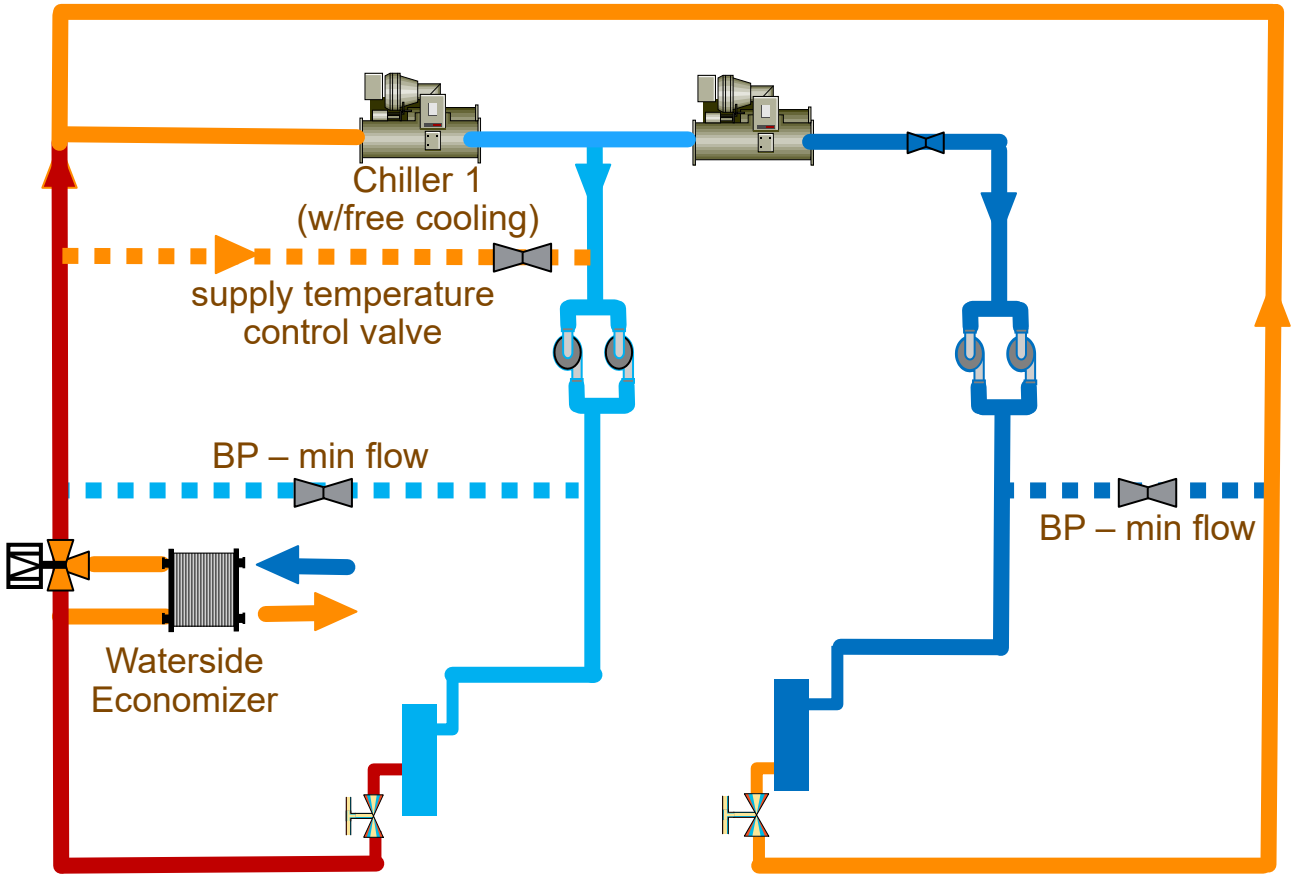


Dual-Temperature Plants

Other Options

- Series Loads
- Split Flow
  - ↑ Upstream chiller flow
  - ↑ Efficiency
  - ↑ Pressure drop
  - ↑ Pump energy

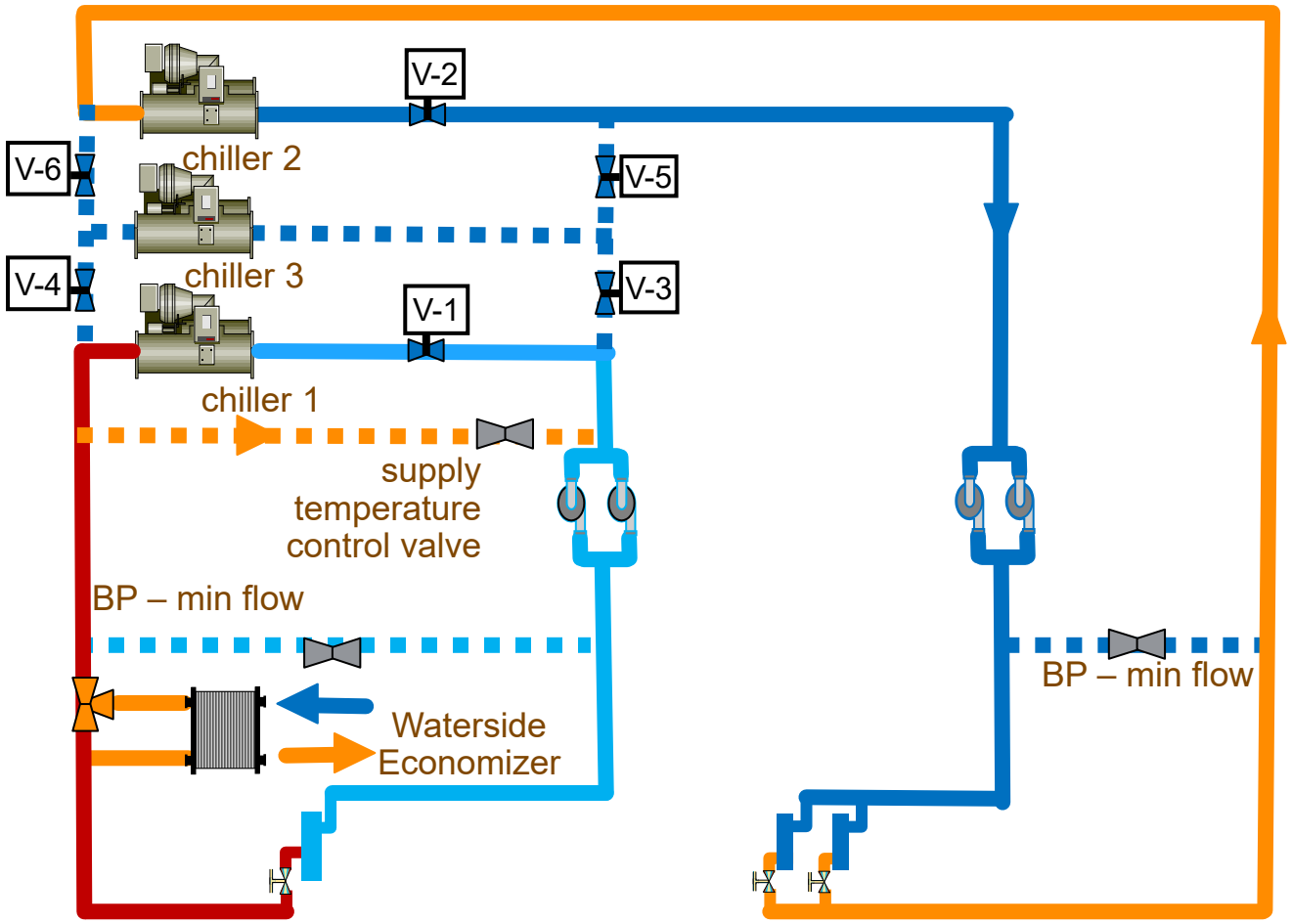
- Cold load return must not be colder than upstream chiller temp



Dual-Temperature Plants

Other Options

- Series Loads
- Split Flow
- Dedicated chillers
  - Optimized chillers
  - Fail safes
    - ↑ Redundancy
    - ↑ Complexity
    - ↑ Control

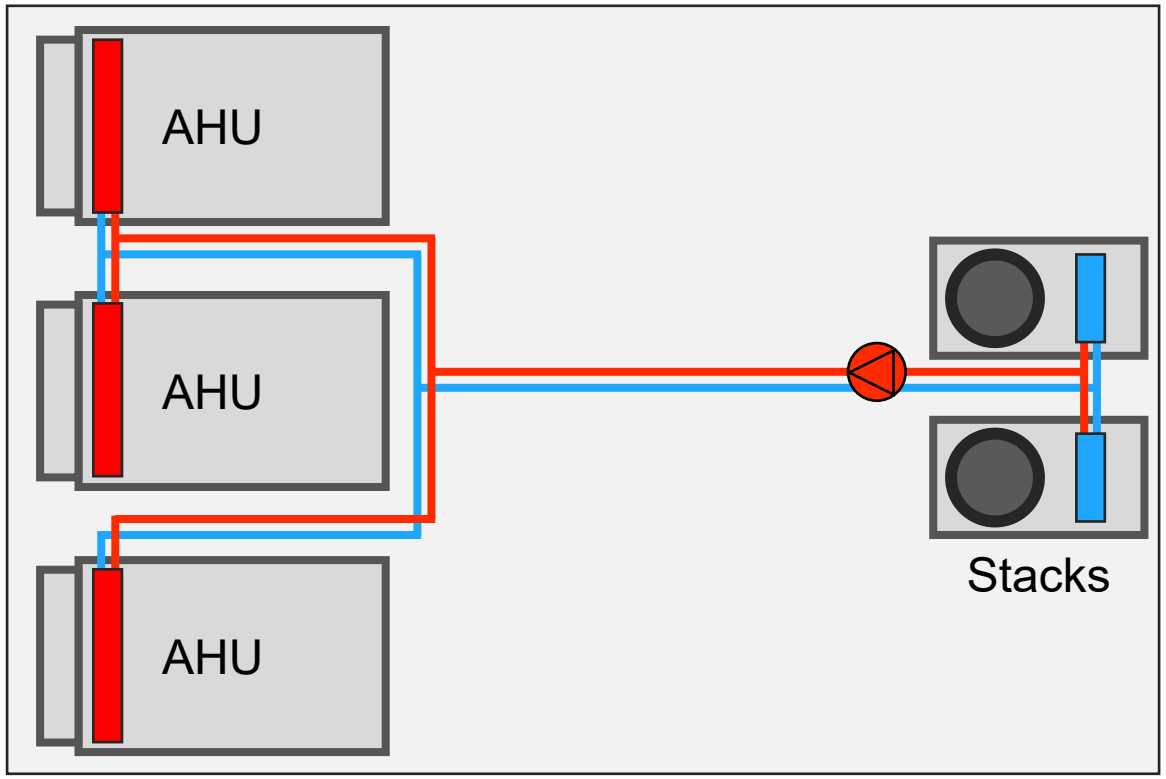


Dual-Temperature Plants

- Parallel vs series chillers
- Load configuration
- Redundancy

Trane Solutions

Trane Remote Energy Recovery System



Winter Operation

- Remote energy recovery
- Pre-heat, pre-cool outdoor air
- Factory-mounted coils
- Field-installed pumps, piping, valves, controls
- Different, unique configurations
  - One-to-one
  - One-to-many, many-to-one, many-to-many
- Advanced selection and sizing software
- Energy, carbon reduction, and economic modeling

What Do Life Sciences Customers Want?

Uptime

Reliability

Efficiency

First cost

Scalability

Trane Technologies' Solutions

Ultra Low Chamber
- 190 ft^3 capacity
- Setpoint: -4°F to -112°F

Ultra Low Pallet Chamber
- 311 ft^3 capacity
- Setpoint: -4°F to -94°F

Farrar Scientific

SuperFreezer™
- 10- and 20-foot offerings
- Setpoint: 10°F to -94°F

THERMO KING

Trane Chillers
- 20 – 4,000+ tons
- Heat recovery, heat pump, Free cooling
- Modular models

Trane Climate Changers
- 1,000 – 200,000+ cfm
- ATA energy recovery, CDQ

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Thank you!

Questions?