LEADING THE WAY
CampusEnergy2022

Feb. 15-18 | Westin Boston Seaport District Hotel | Boston, Mass.

INTERNATIONAL DISTRICT ENERGY ASSOCIATION

Application of District Energy Principles for Enabling Energy and Exergy Efficiency, Conservation of Energy and Mass, and Promoting Safety and Hygiene in Multistory Potable-water Systems

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Background story

Vertically Integrated Systems in Stand-Alone Multistory Buildings

By Robert Bean, Associate Member ASHRAE, **Tim Doran,** Member ASHRAE, **Bjarne Olesen, Ph.D.,** Fellow ASHRAE, and **Peter Simmonds, Ph.D.,** Member ASHRAE

The term district energy typically is considered horizontal municipal heating/cooling and domestic piping systems linking thermal production to consumption (*Figure 1*). An alternative approach is to take the system and rotate it 90° to service stand-alone multistory buildings (*Figure 2*).

This involves having production units distribute to the consuming units through a single vertical and central distribution network. Each floor is served by an indirect connected substation (*Figure 3*). Enhancing comfort[1] and reducing energy demand[2] is possible when floor-to-floor (rather than building-to-building) consumption is moderate (cooling) or low (heating) temperature radiant-based surface conditioning systems are used (possibly with dedicated outdoor air systems). This is particularly true when the design considers activating the building floor mass as a thermal capacitor.

In a vertically integrated system, the heating and cooling plant acknowledges the low-temperature requirements associated with radiant-based systems and is designed to take advantage of condensing or renewable technologies or use standard boiler and chiller equipment.

As noted by Olesen, "Hydronic concrete slab cooling and heating systems can use relative high water temperatures for cooling and relative low water temperature for heating. This increases the possibility of using renewable energy sources such as ground heat exchangers, solar energy for heating and cooling and free night cooling. It also increases the efficiency of boilers, refrigeration machines and heat pumps (Steimle, 1999). On top of that the active concrete system may

About the Authors

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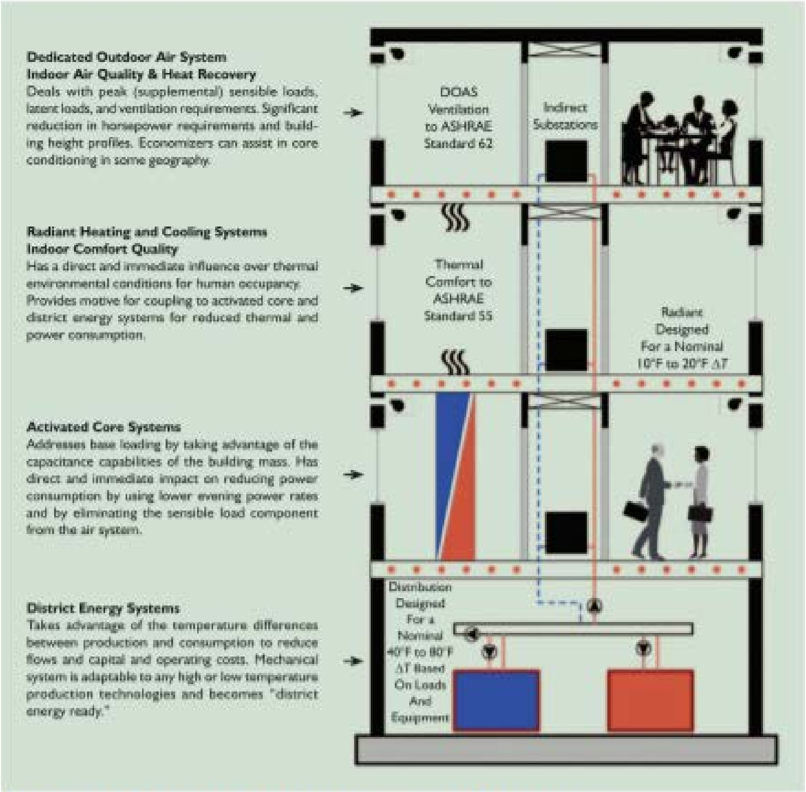


Summary and benefits of vertically integrated systems (simplified illustration).

use cheaper night rate electricity."[2]

As stated in the *2004 ASHRAE Handbook—HVAC Systems and Equipment*, "Central plants generally have efficient base-load units and less costly peaking equipment for use in extreme loads or emergencies."[3]

Regardless of the plant selection, the potential operating temperature differential between production and consumption could reduce distribution flows significantly. For heating, floors are limited to less than 84°F (29°C) surface temperatures and for cooling, above 66°F (19°C) (ANSI/ASHRAE Standard 55-2004, *Thermal Environmental Conditions for Human Occupancy*). Therefore, plants operating at 180°F (82°C) or chillers at 42°F (6°C) have significant motive force for heat transfer.

Example (*Figure 4*): Given a 1.5 MBtu/h (440 kWh) direct-connected heating load, operating with traditional baseboard or fan/coil units, 180°F (82°C) entering fluid temperatures, and a design ΔT of 20°F (11°C) equates to flow using:

$$Q_w = q_w / (60 \text{ min/h} \times p_w \times C_p \times \Delta T)$$

where

Q_w = flow, gpm (L/s)
q_w = heat transfer, Btu/h (kWh)
p_w = fluid density, lb/gal, (kg/m^3) (e.g., I-P units 8.2 at 150°F, 8.1 at 180°F)
C_p = specific heat, Btu/lb · °F, (kJ/kg · K)
Q_w = 1.5 MBtu/h/(60 min/h × 8.1 lb/gal × 1 Btu/lb · °F × 20°F)
Q_w = 155 gpm (9.46 L/s)

To stay within friction losses of 1 ft (0.31 m) to 4 ft (1.22 m) per 100 ft (31 m) of pipe and flow velocities of 2 fps (0.61 m/s) to 5 fps (1.5 m/s), the primary distribution pipe would be a 4 in. (100 mm) line.

However, (independent of discussions on energy production efficiencies), plants running at maximum design with weather-compensated target supply temperatures of 180°F (82°C), indirectly connected to a radiant system operating with a sec-

What can we do about potable systems?

Reduce energy storage & bacteria in domestic water piping systems

Reduce primary piping transmission heat losses with fewer risers

Reduce primary piping chase space & associated capital & labor costs

Create smaller localized domestic water networks

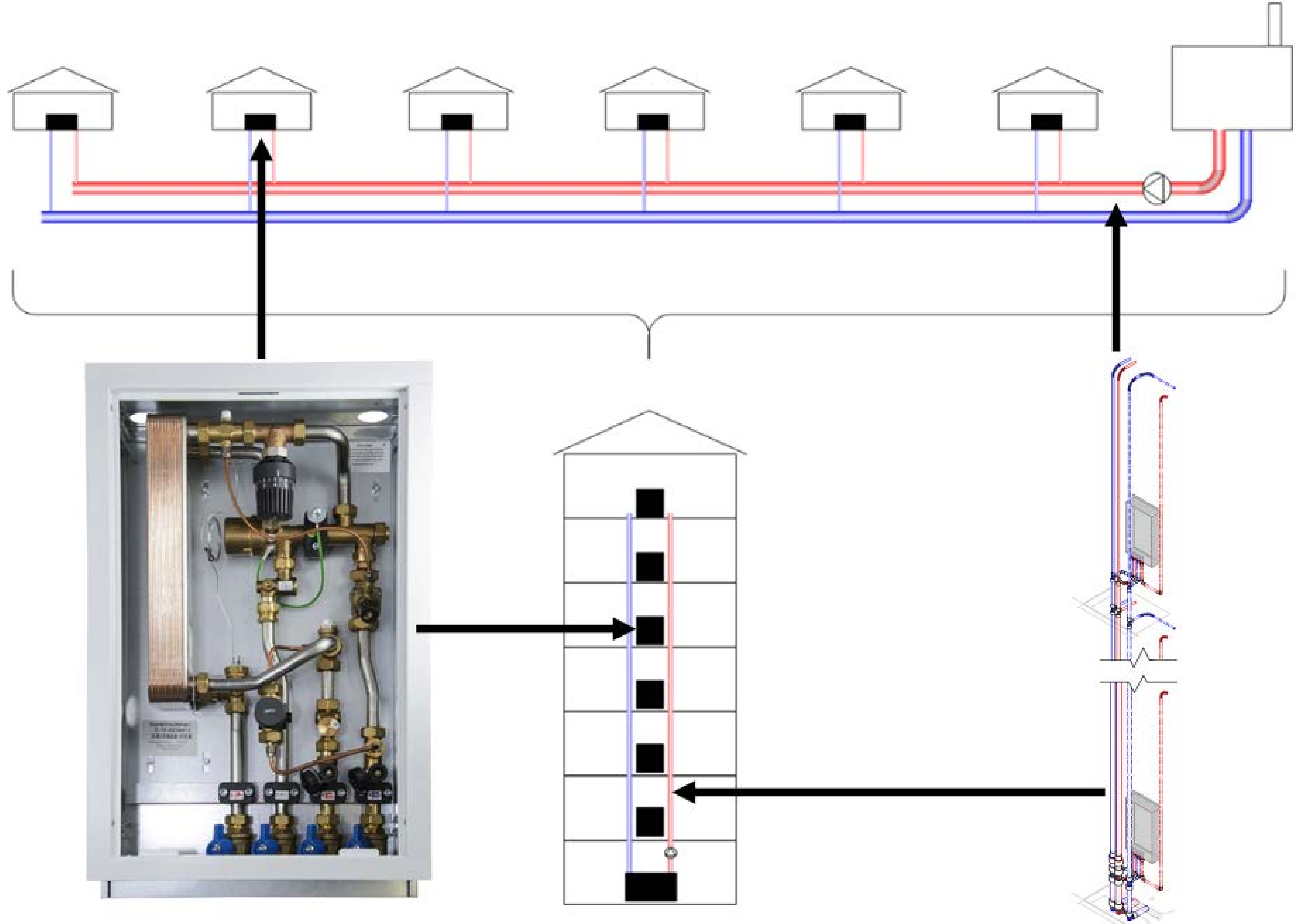
Provide individualized domestic heated water on demand

Enable adaptation to district energy retrofits

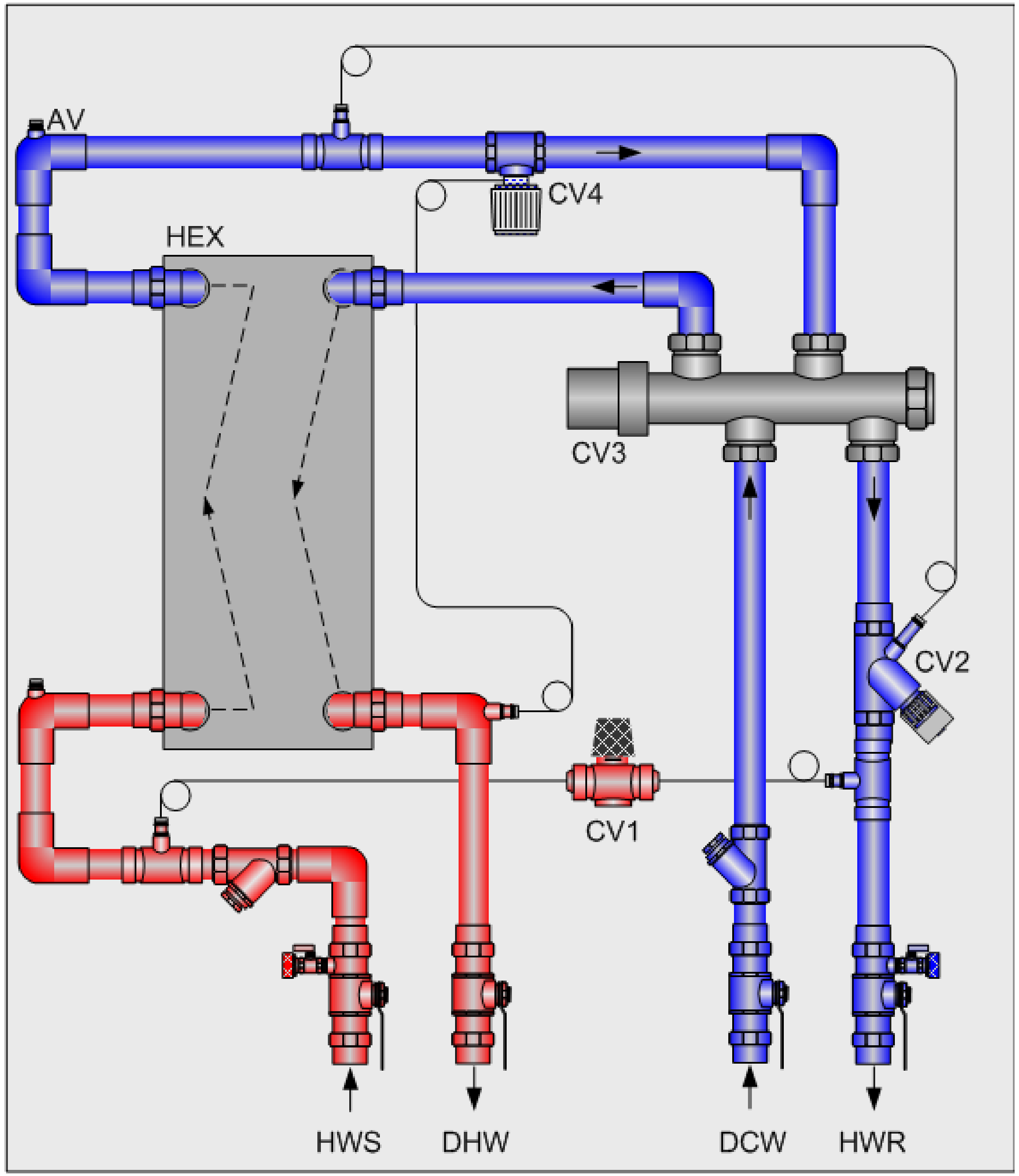
Select exchangers for lowest return temperatures for energy efficiency

Optimize systems for use with renewable energy for exergy efficiency

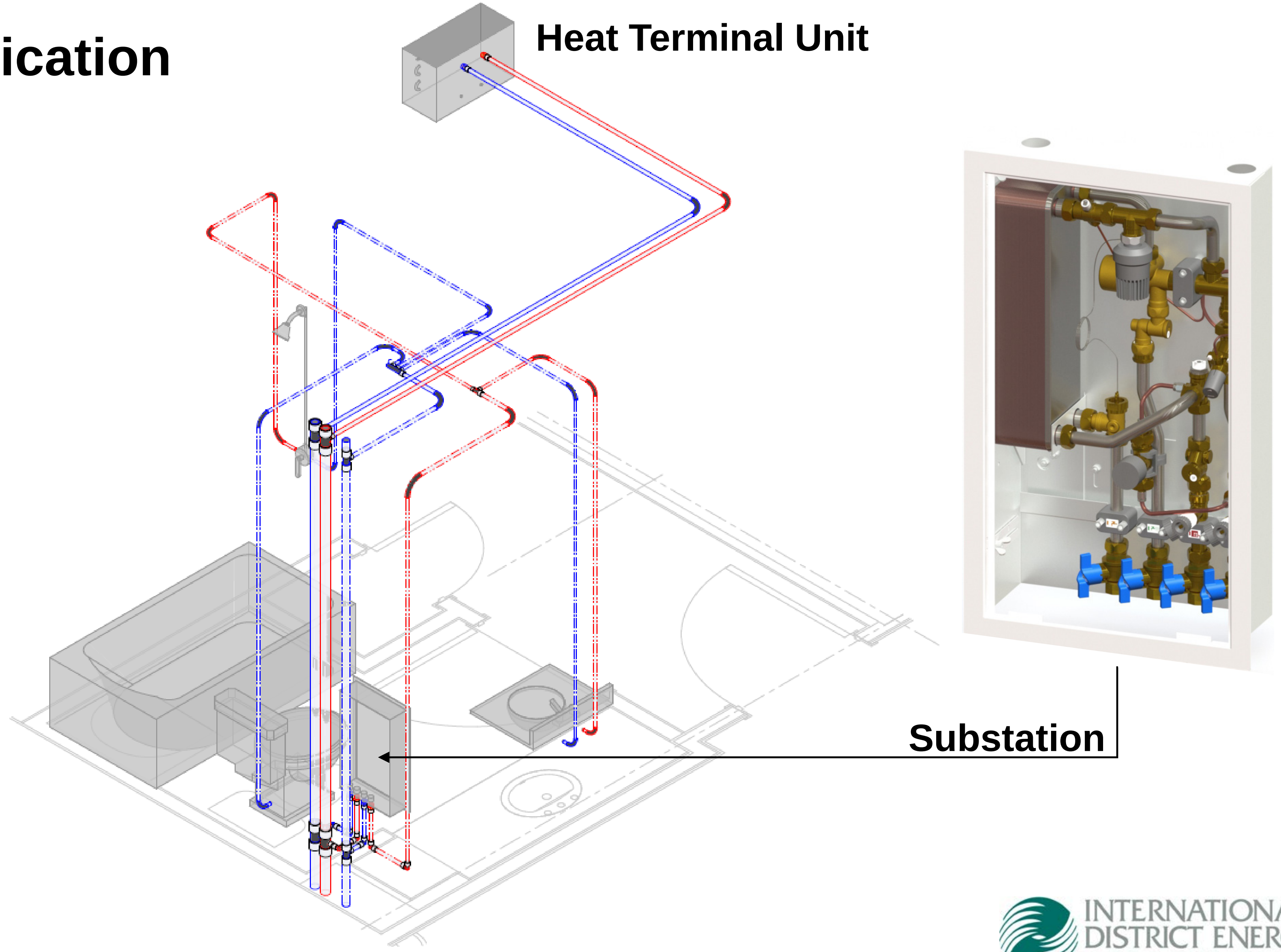
Strategy…use an old, simple & timeless approach that works



Substation



Typical Application

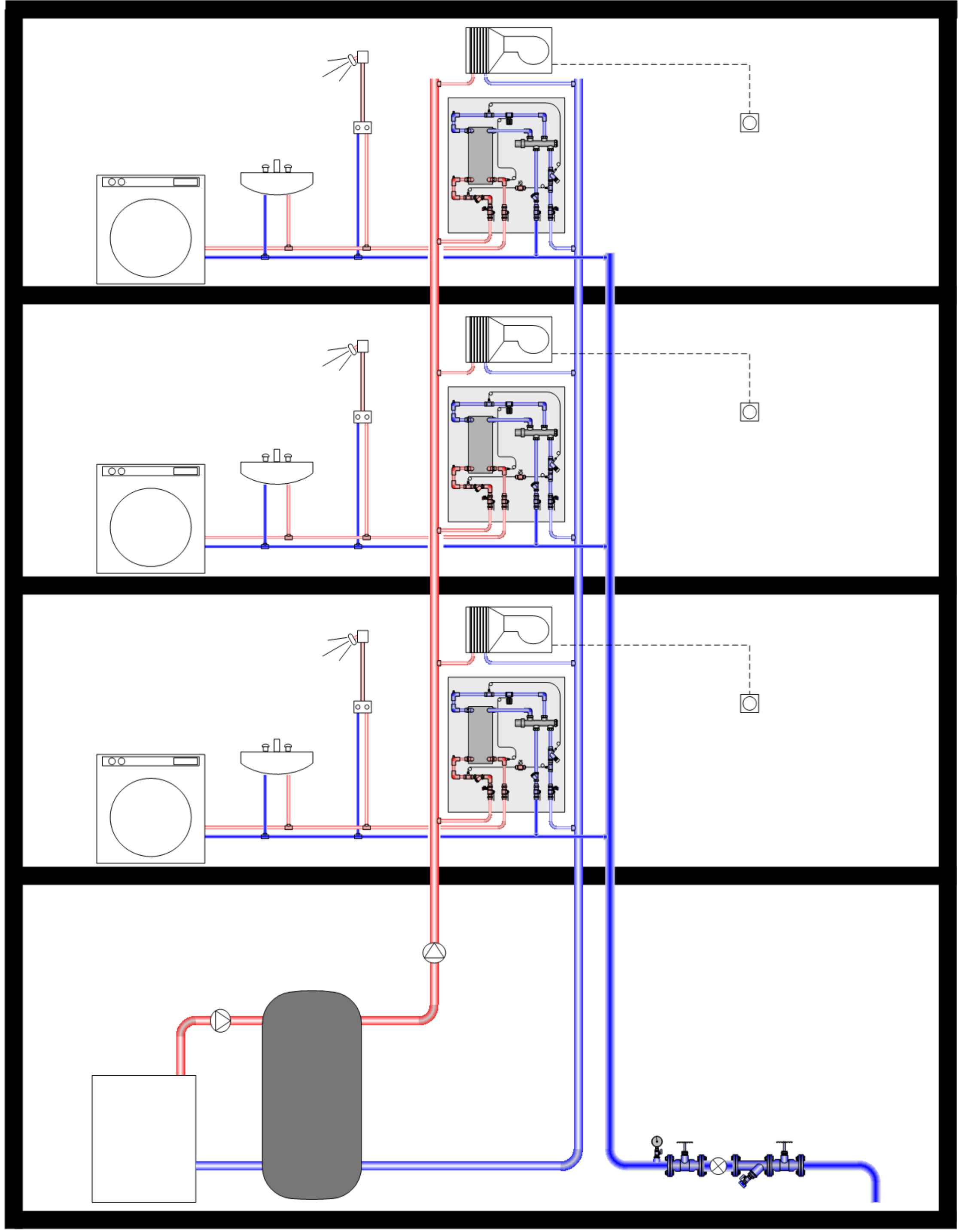


Typical Application

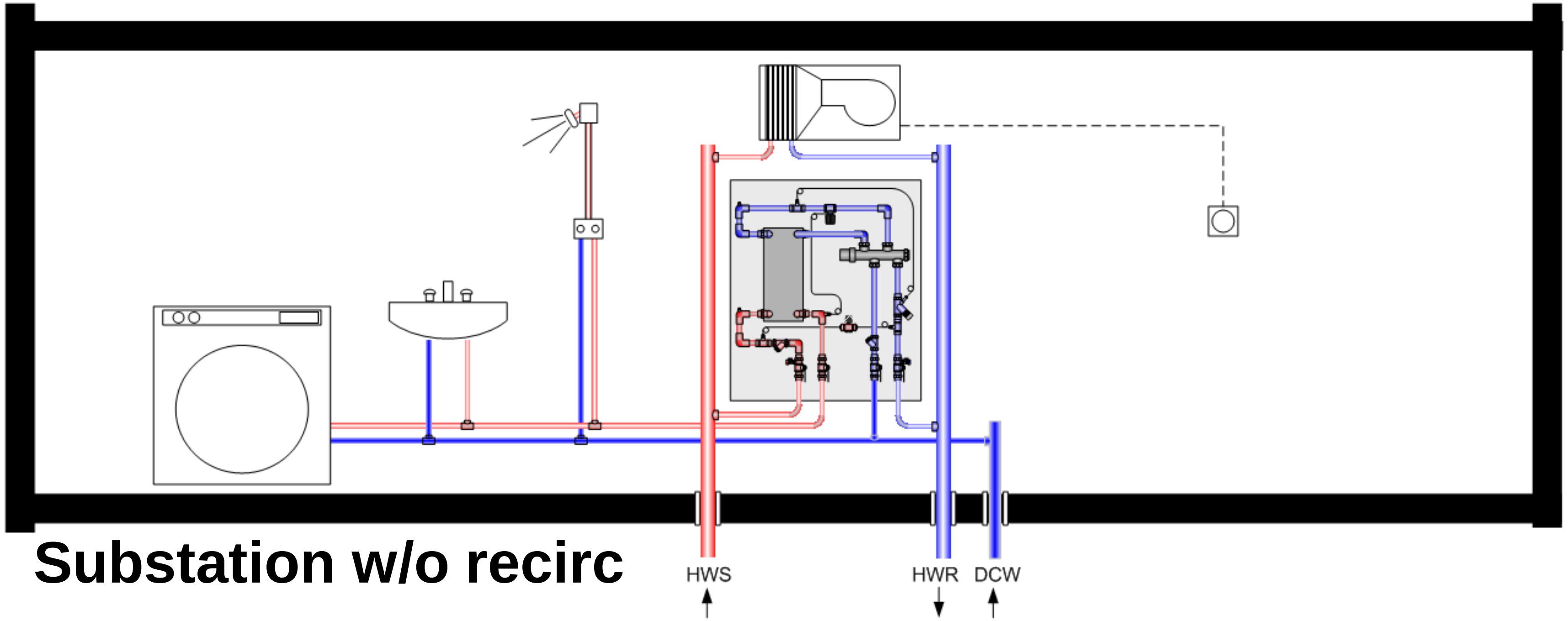
Substations

Typical Application

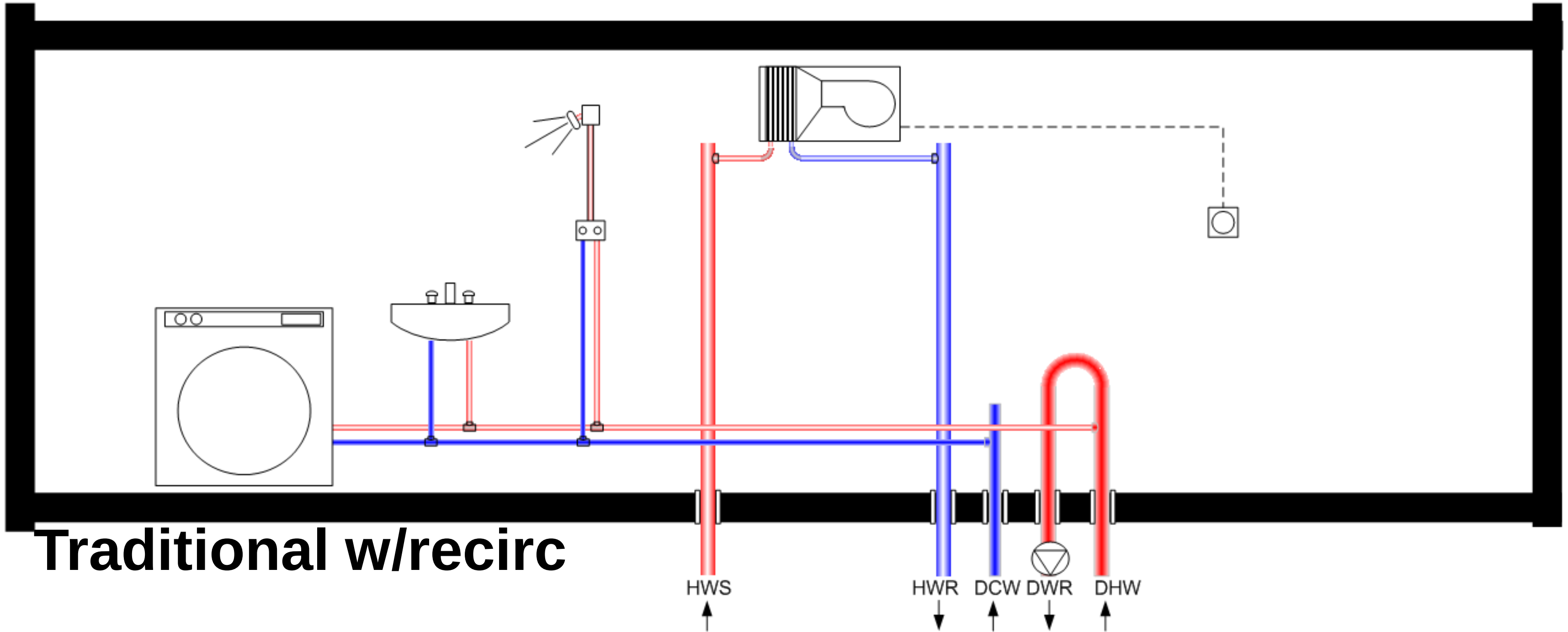
Distribution



Distribution

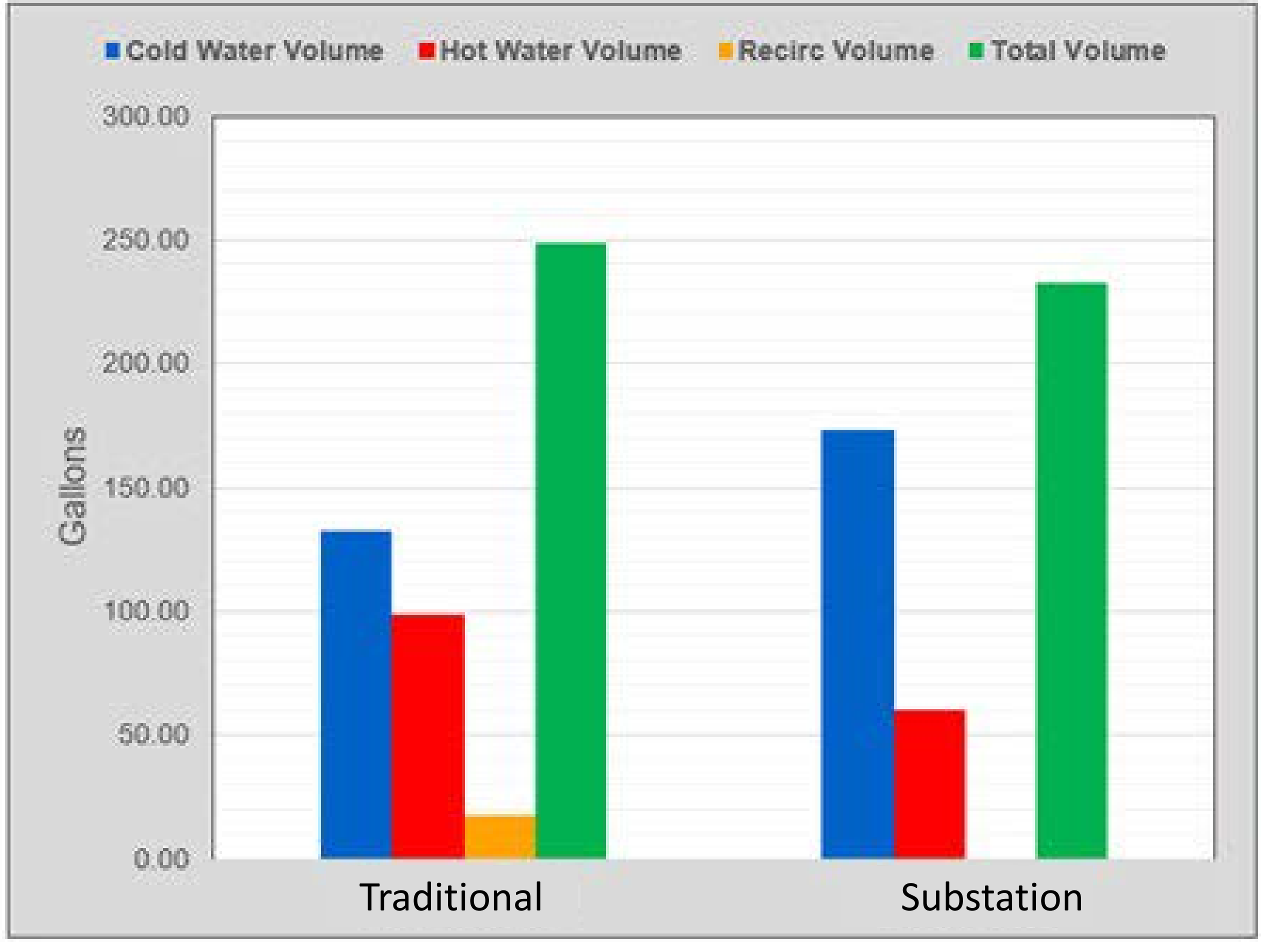


Substation w/o recirc



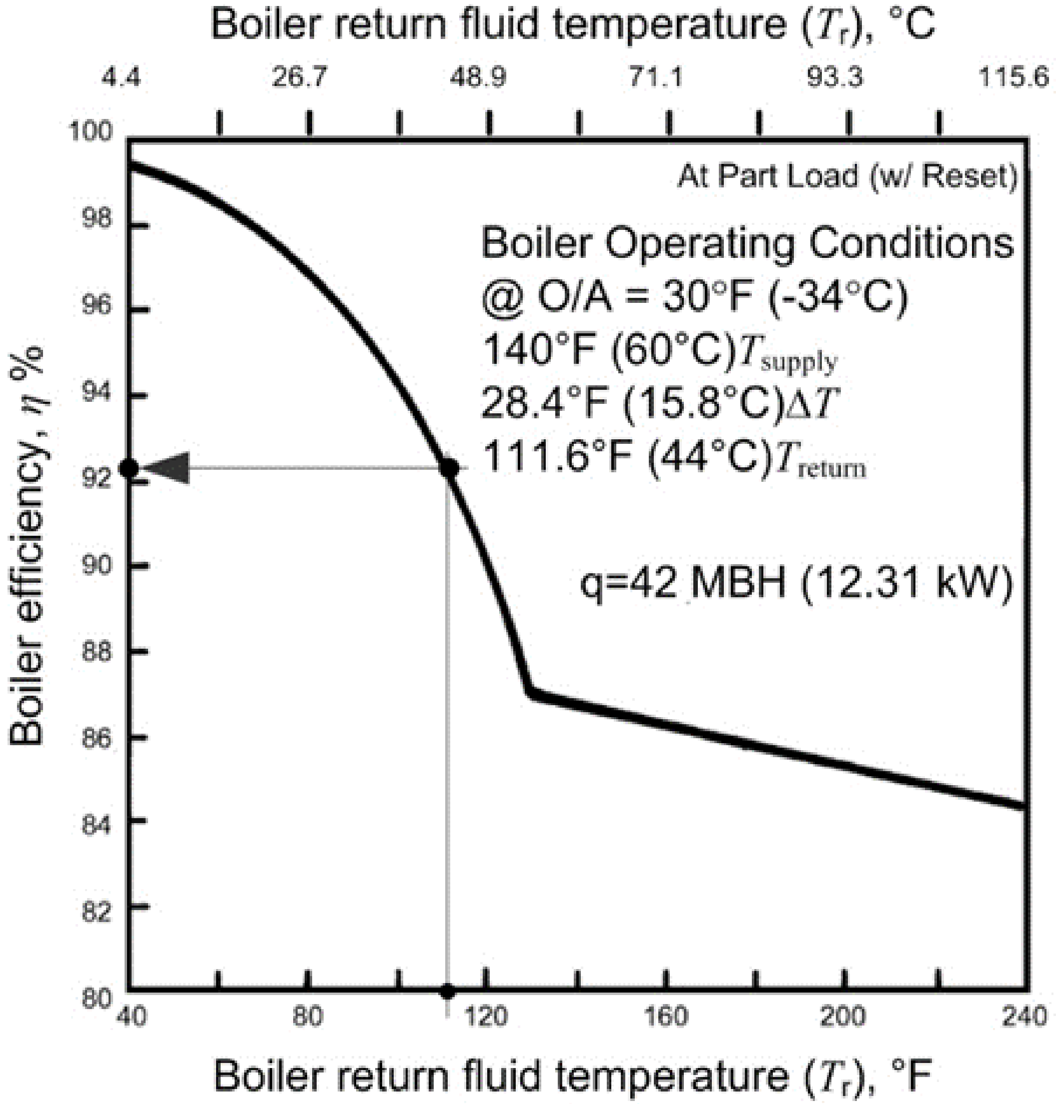
Traditional w/recirc

Distribution: volume & piping surface area reduction

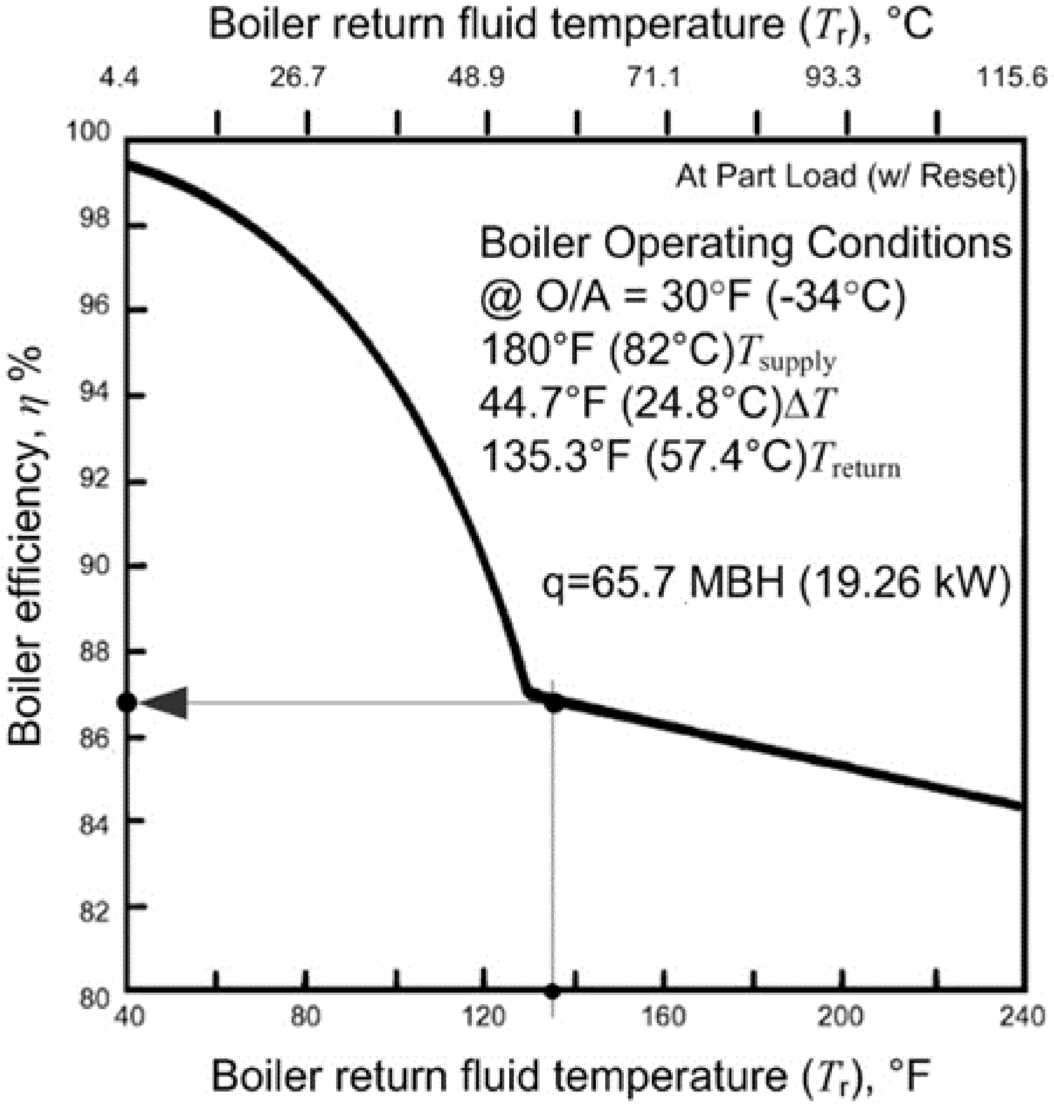


System Volume Delta		
Domestic CW Delta		
-40.58	Gallons	31%
-338.02	lbs	31%
-93.34	sq.ft.	8%
Domestic HW Delta		
56.41	Gallons	-49%
469.86	lbs	-49%
289.87	sq.ft.	-30%
Total System Volume Delta		
15.83	Gallons	-6%
131.84	lbs	-6%
196.53	sq.ft.	-9%

Heat exchanger selection: optimize for lowest return temperature



Coil A – Operating Condition 1

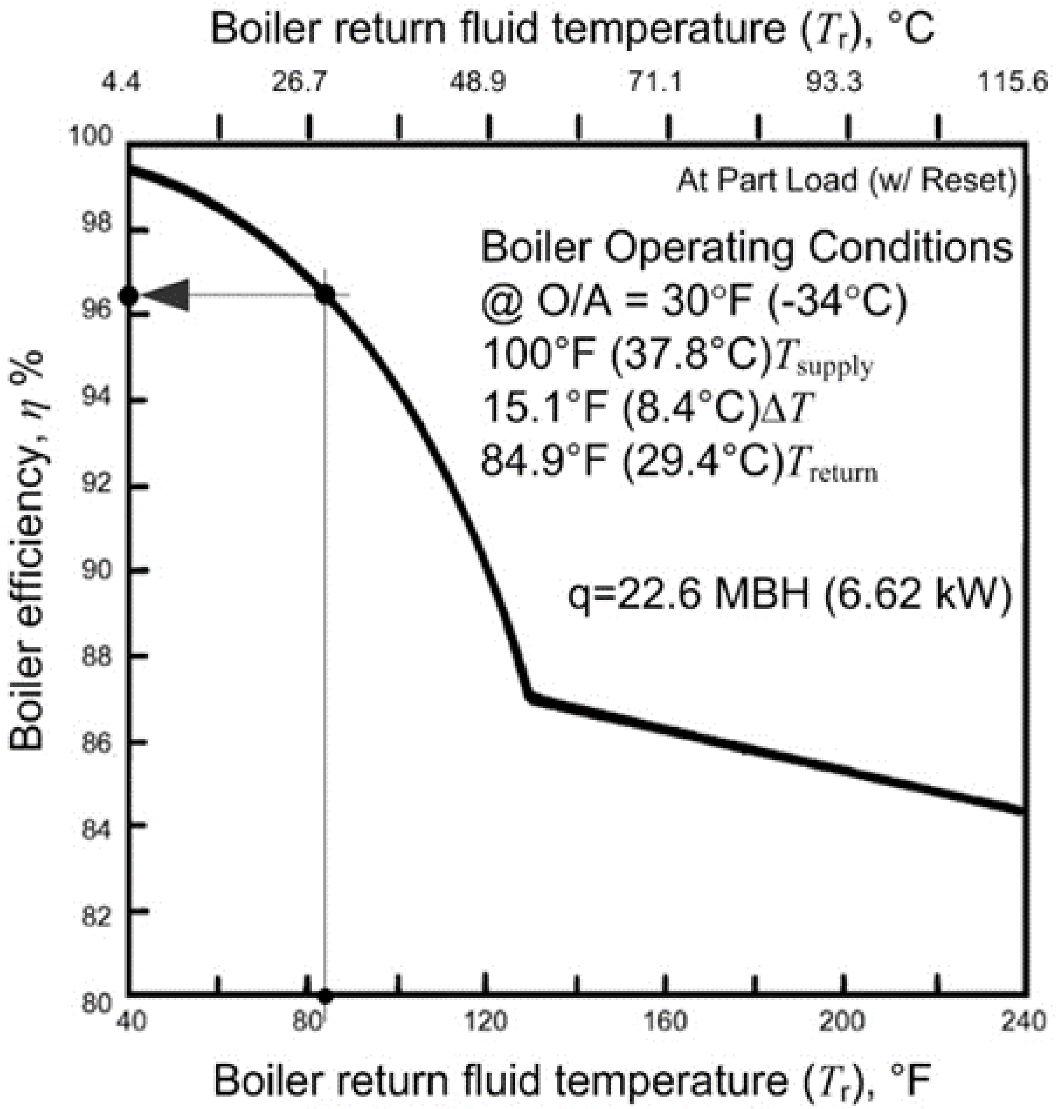


Coil A – Operating Condition 2

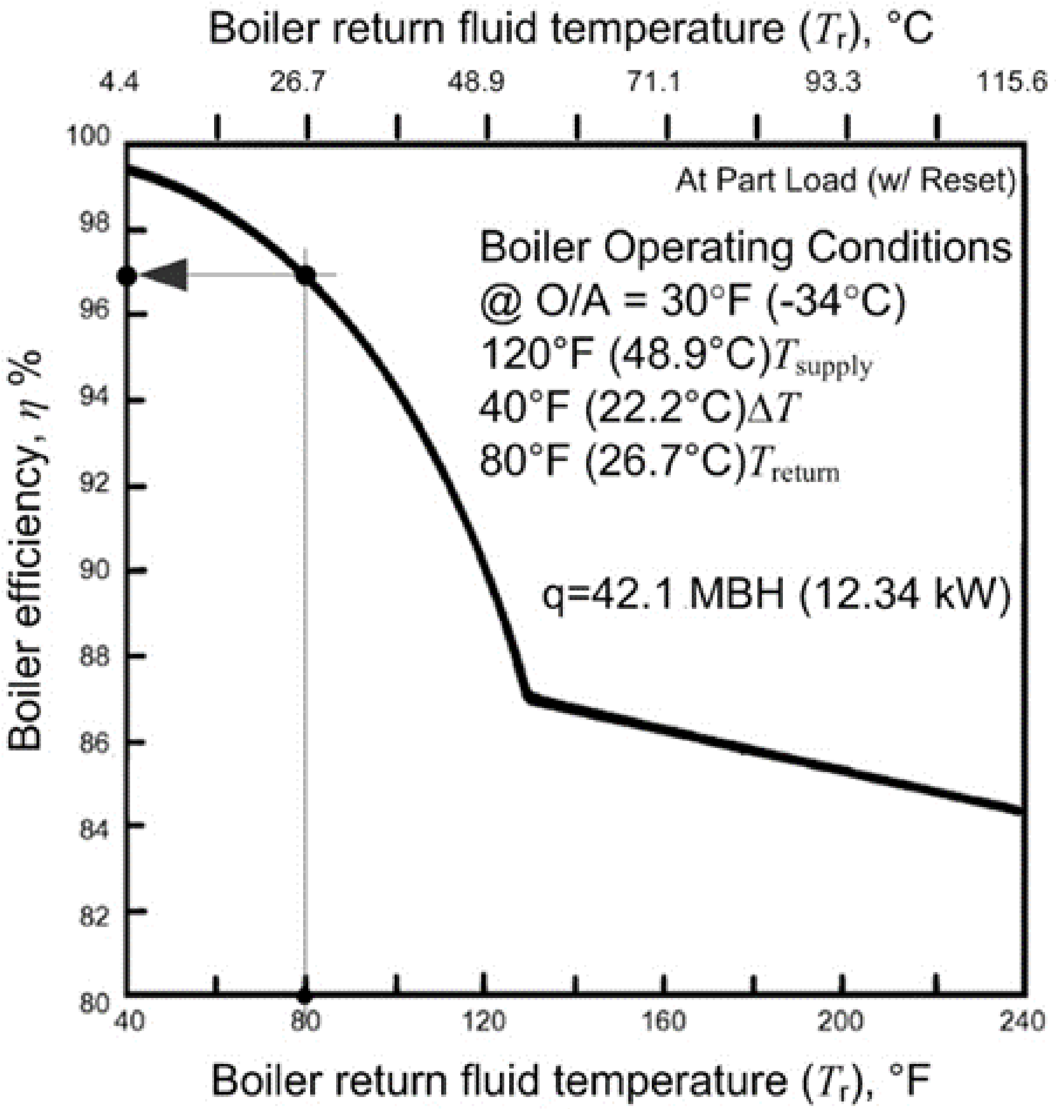
heating fan/coil

Source: Bean, R., 2016. The effect of heating coil performance on boiler efficiency and system complexity. HPAC Magazine Canada

Heat exchanger selection: optimize for lowest return temperature



Coil A – Operating Condition 3



Coil B

heating fan/coil

Source: Bean, R., 2016. The effect of heating coil performance on boiler efficiency and system complexity. HPAC Magazine Canada

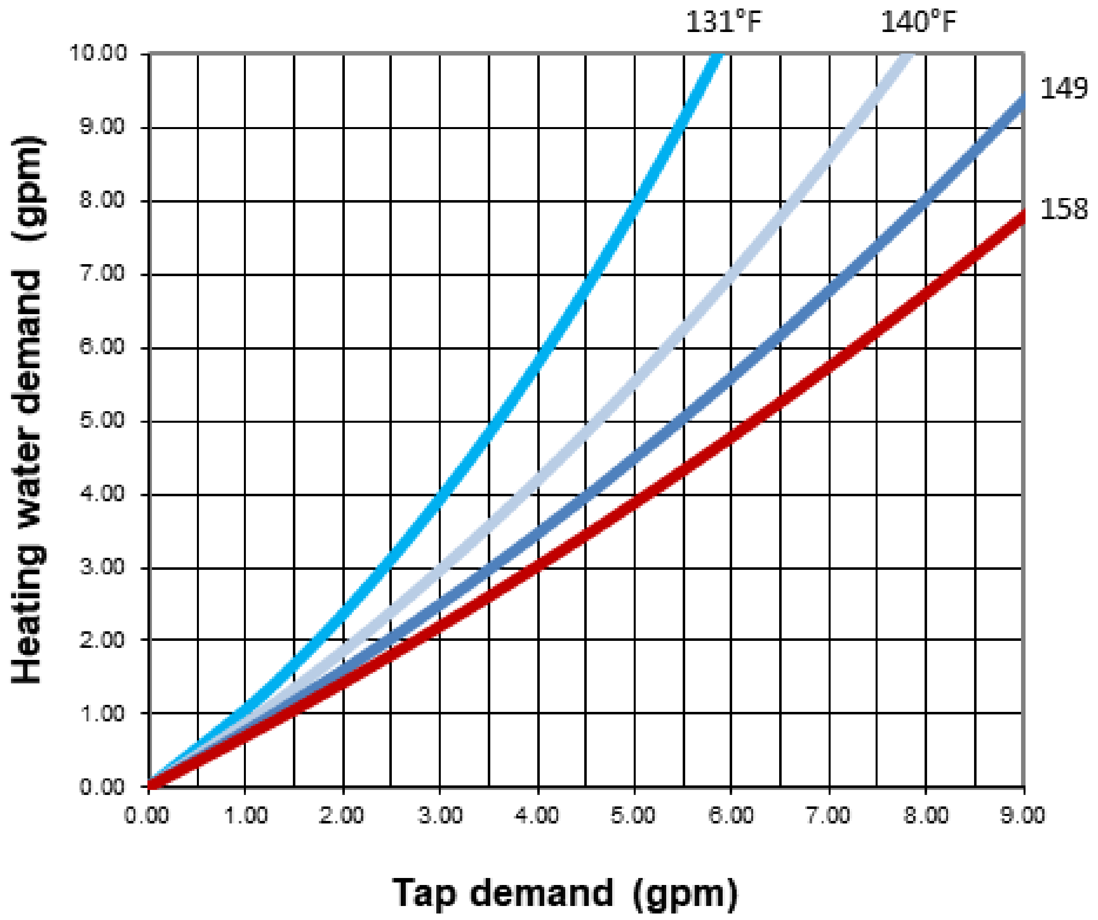
Heat exchanger selection: optimize for lowest return temperature

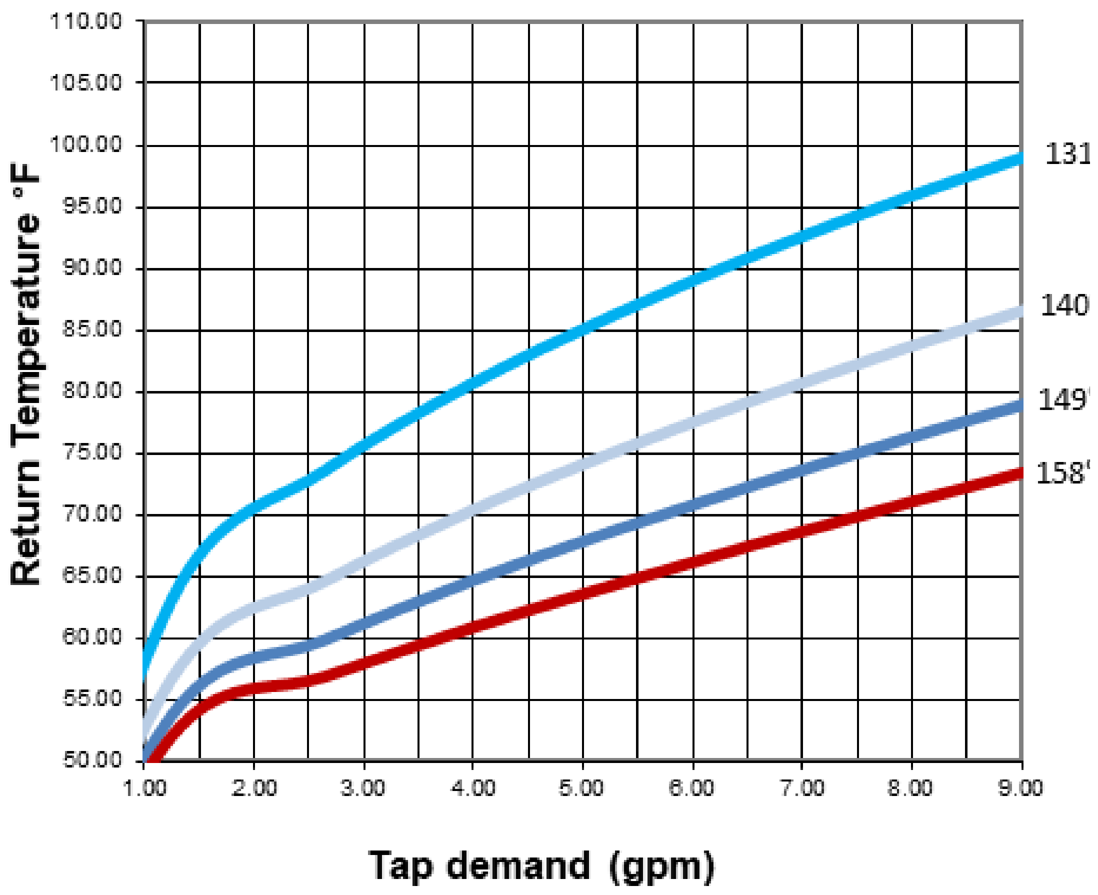
Table 2. Specific Coil Characteristics and Performance Comparison				
Coil	A	B	C	D
Entering dry bulb (°F)	55.00	55.00	55.00	55.00
Leaving dry bulb (°F)	93.80	115.70	75.80	93.90
Entering fluid temp. (°F)	140.00	180.00	100.00	120.00
Leaving fluid temp. (°F)	111.60	135.30	84.90	80.00
Fluid flow rate (GPM)	3.00	3.00	3.00	2.10
Fluid pressure drop (ft of water)	1.20	1.10	1.20	3.60
Total capacity (MBH)	42.00	65.70	22.60	42.10
LMTD (°F)	51.22	72.00	26.95	25.55
Estimated boiler efficiency, n%	92.50	86.50	96.25	97.00

Coil D: one-time capital cost increase for lifetime of energy & exergy efficiency benefits

Source: Bean, R., 2016. The effect of heating coil performance on boiler efficiency and system complexity. HPAC Magazine Canada

Heat exchanger selection: optimize for lowest return temperature





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domestic water double walled brazed plate

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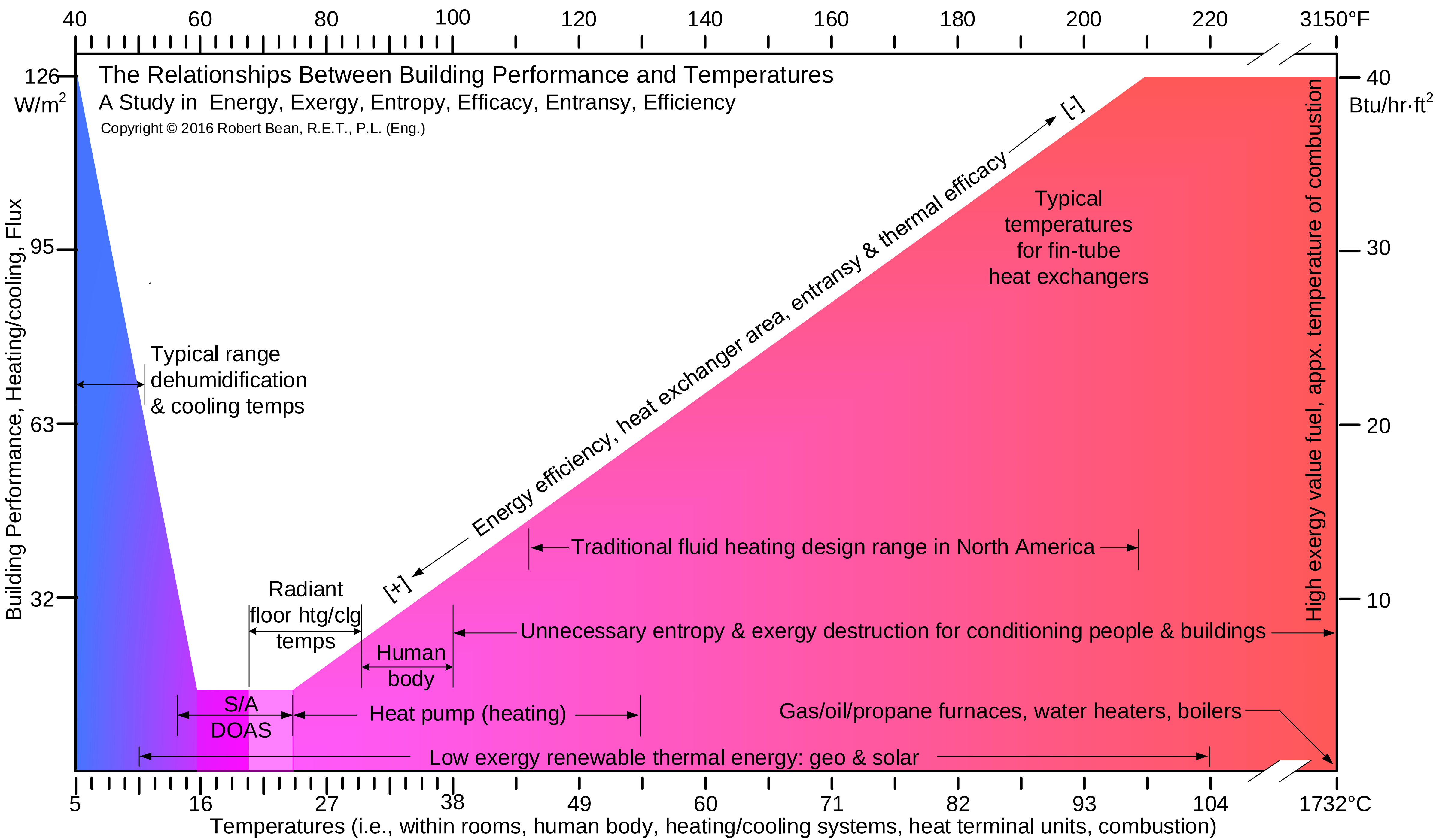
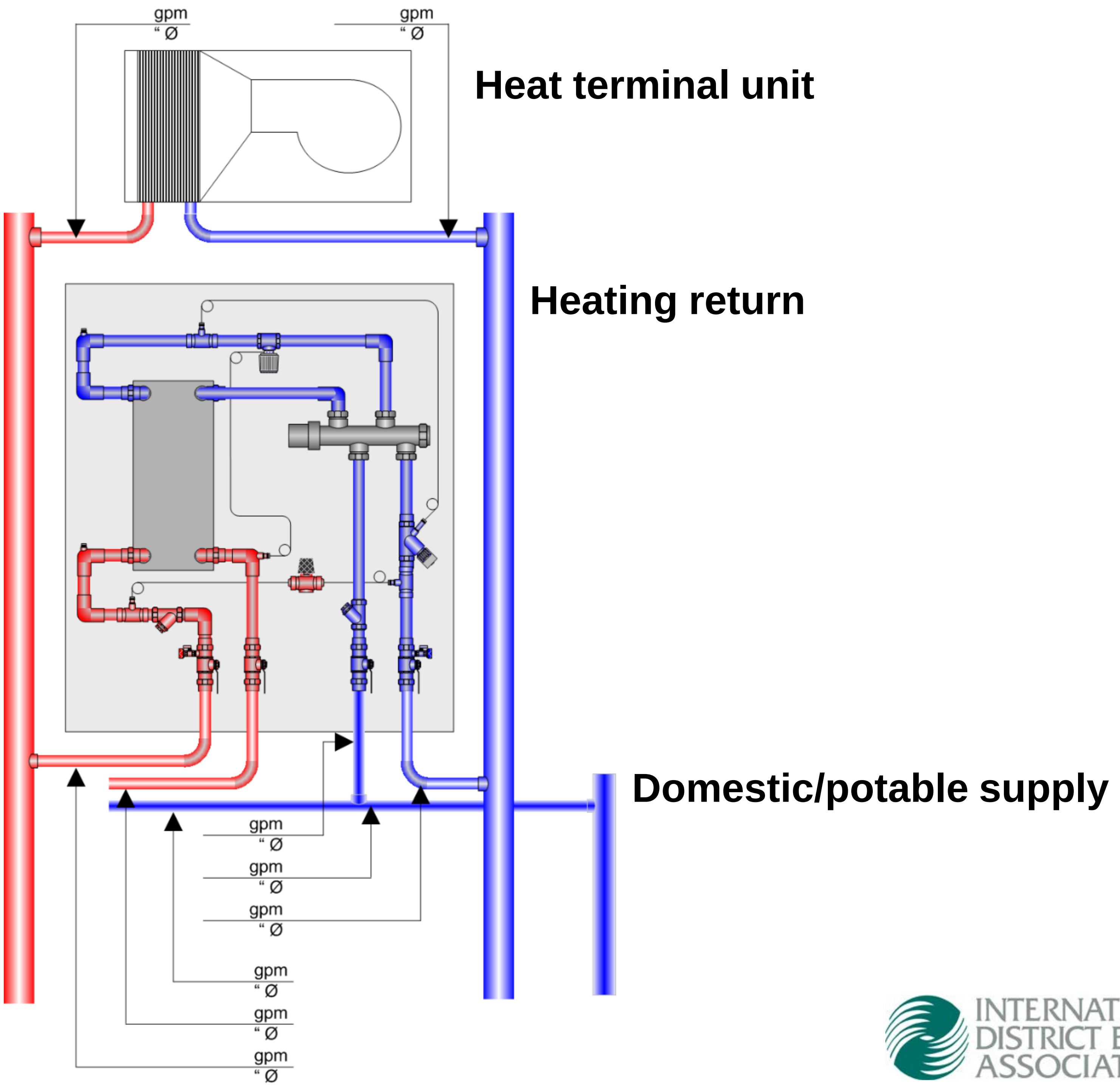


The Relationships Between Building Performance and Temperatures
A Study in Energy, Exergy, Entropy, Efficacy, Entransy, Efficiency
Copyright © 2016 Robert Bean, R.E.T., P.L. (Eng.)
40 60 80 100 120 140 160 180 200 220 3150°F
5 16 27 38 49 60 71 82 93 104 1732°C
Temperatures (i.e., within rooms, human body, heating/cooling systems, heat terminal units, combustion)
126 W/m2
95
63
32
Building Performance, Heating/cooling, Flux
40 Btu/hr·ft2
30
20
10
High exergy value fuel, appx. temperature of combustion
Energy efficiency, heat exchanger area, entransy & thermal efficacy
[+]
[-]
Typical temperatures for fin-tube heat exchangers
Typical range dehumidification & cooling temps
Traditional fluid heating design range in North America
Radiant floor htg/clg temps
Unnecessary entropy & exergy destruction for conditioning people & buildings
Human body
S/A DOAS
Heat pump (heating)
Gas/oil/propane furnaces, water heaters, boilers
Low exergy renewable thermal energy: geo & solar

Dimensioning



Typical Flow & Temperature Demands from Domestic Load

Ref.: IPC / UPC Codes for water supply fixture units (WSFU), max vel. 10 fps, PEX pipe

Table 2: Typical design flows and temperature demands (ref.: DIN VDI 6003)

Load	Performance Class, Flow, l/min (U.S. gpm)			Temperatures C (F)
	Level 1	Level 2	Level 3	
Sink	3 (0.80)	5 (1.32)	6 (1.59)	40 (104)
Shower	7 (1.85)	9 (2.38)	9 (2.38)	42 (108)
Bathtub	7 (1.85)	10 (2.64)	13 (3.43)	45 (113)
Kitchen sink	3 (0.80)	5 (1.32)	6 (1.59)	50 (122)
Bidet		3 (0.80)	3 (0.80)	40 (104)
Large bathtub		13 (3.43)	13 (3.43)	50 (122)

Source: Bean, R., Stotko, A., Koppi, A., Wiedemann, J., Finch, J., Bliss, K., Folkedahl, M., (2021) Centralized Plants with Decentralized Solutions Using Substations for Enabling Energy and Exergy Efficiency, Conservation of Energy and Mass, and Promoting Safety and Hygiene in Multistory Potable-water Systems. White Paper

Typical Flow & Temperature Demands from Domestic Load

Ref.: IPC / UPC Codes for water supply fixture units (WSFU), max vel. 10 fps, PEX pipe

Enter Your Domestic Water Supply Parameters:				Calculation:
75	Pressure Available at Building		+	100.00 PSI
20	Min. Fixture Working Pressure		-	0.00 PSI
45	Static Loss - System Height (ft.)	0.00 x 0.433	-	0.00 PSI
16	Additional Component Loss		-	0.00 PSI

Available Pressure For Friction Loss = 100.00 PSI

Enter Your Piping Supply Information:			Calculation:
65	Longest Run to Fixture (ft.)	+	0.00 FT
25	Fitting Allowance (% of number above)	+	0.00 FT

Total Developed Length = 0.00 FT

Friction Loss Rate Per Foot (Friction Loss / TDL) = Infinity PSI/FT

Friction Loss Rate per 100 Feet (Friction Loss / TDL * 100) = Infinity PSI/100FT

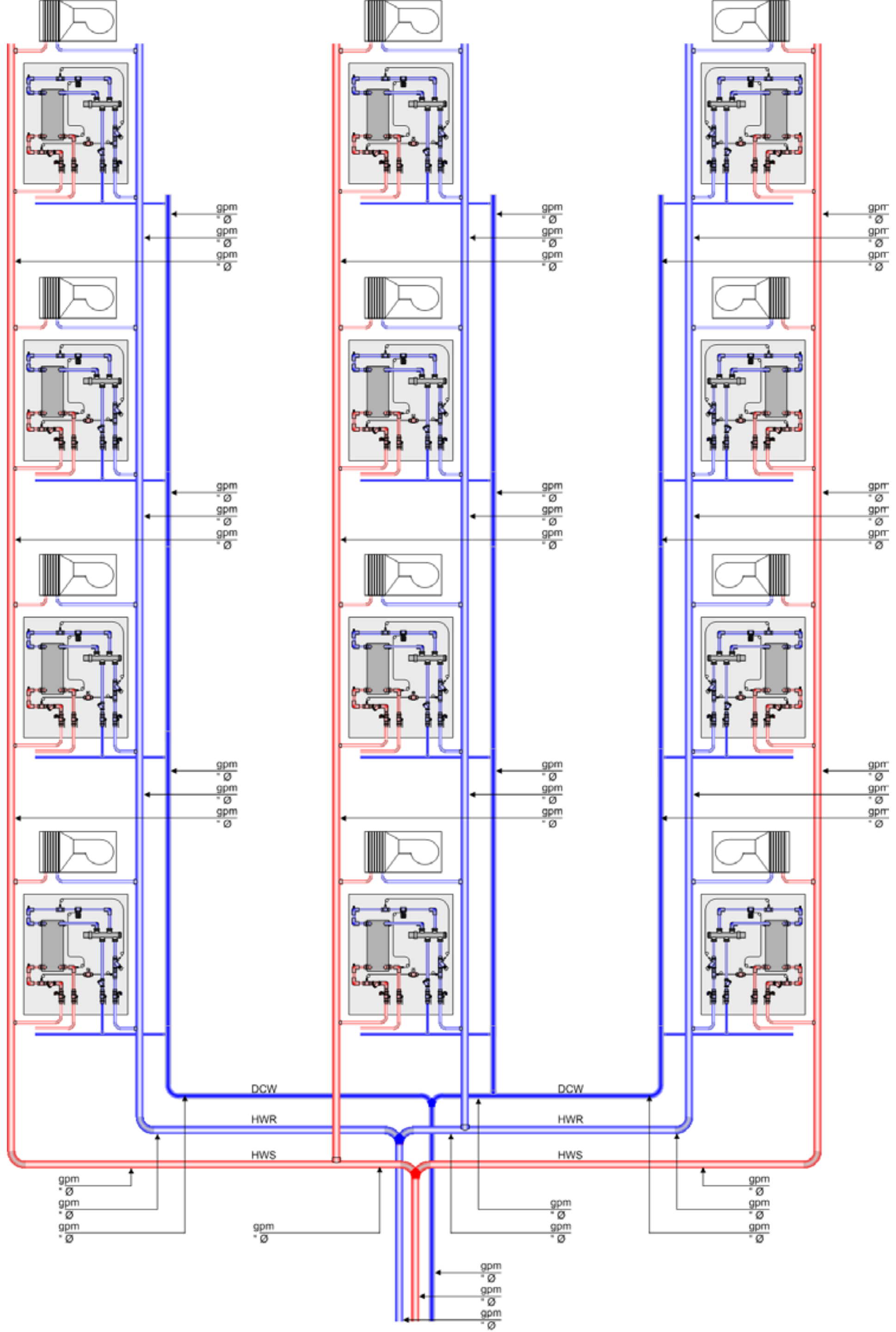
Water Size Chart for PEX:

PEX Water Size Table
IPC - Flush Tank
100% Water @ 60°F
11.710 PSI/100ft.
Max. Velocity = 10 ft./sec.

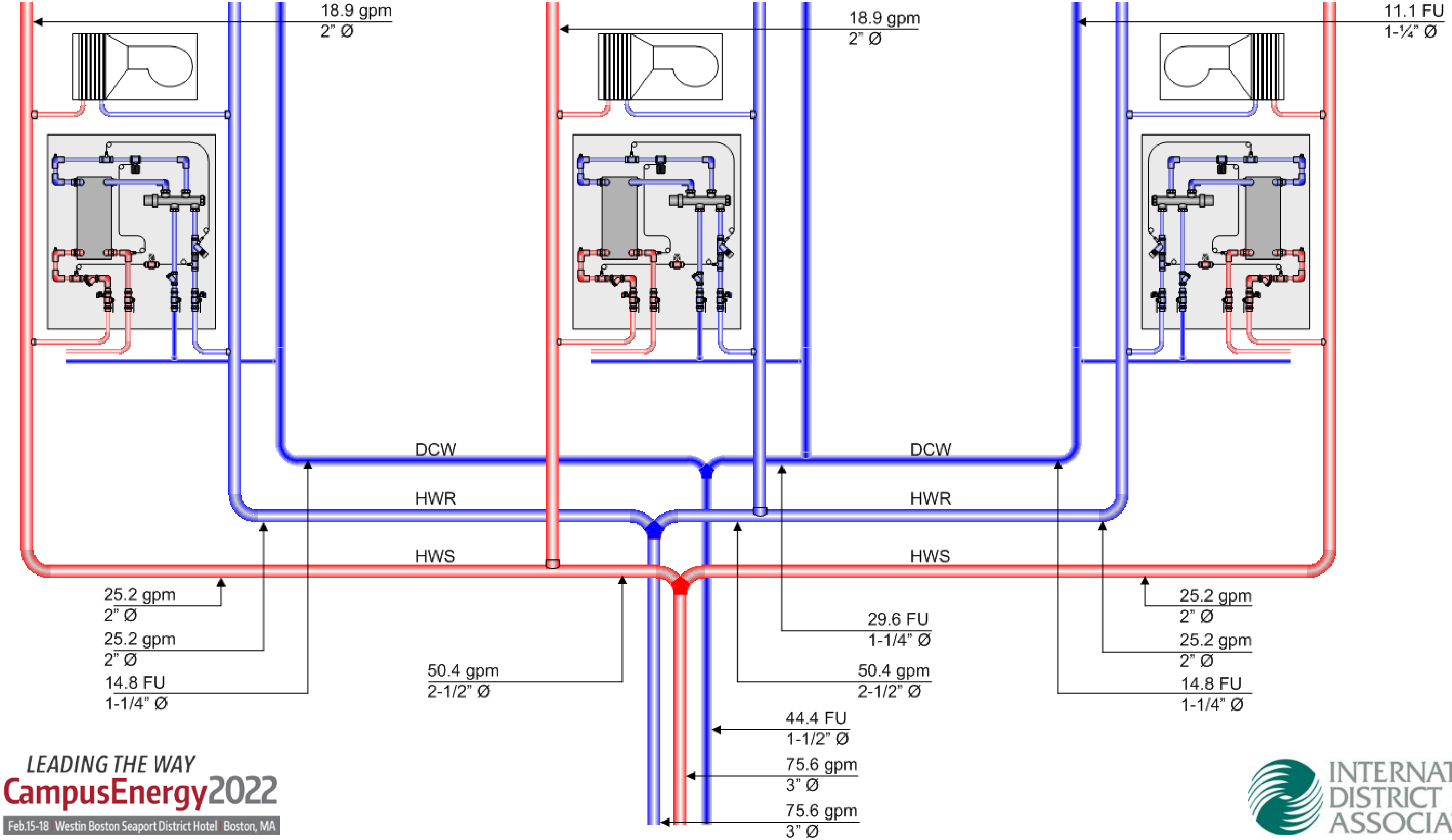
Pipe Size	WSFU Range	Velocity (ft./sec.)	GPM
3/8"	0 -- 0	4.00	1.20
1/2"	0 -- 0	5.00	2.76
3/4"	1 -- 3	6.40	7.05
1"	4 -- 9	7.60	13.83
1 1/4"	10 -- 31	8.70	23.66
1 1/2"	32 -- 77	9.80	37.13
2"	78 -- 199	10.00	64.97
2 1/2"	200 -- 369	10.00	99.01
3"	370 -- 588	10.00	140.79

online flow/velocity tool

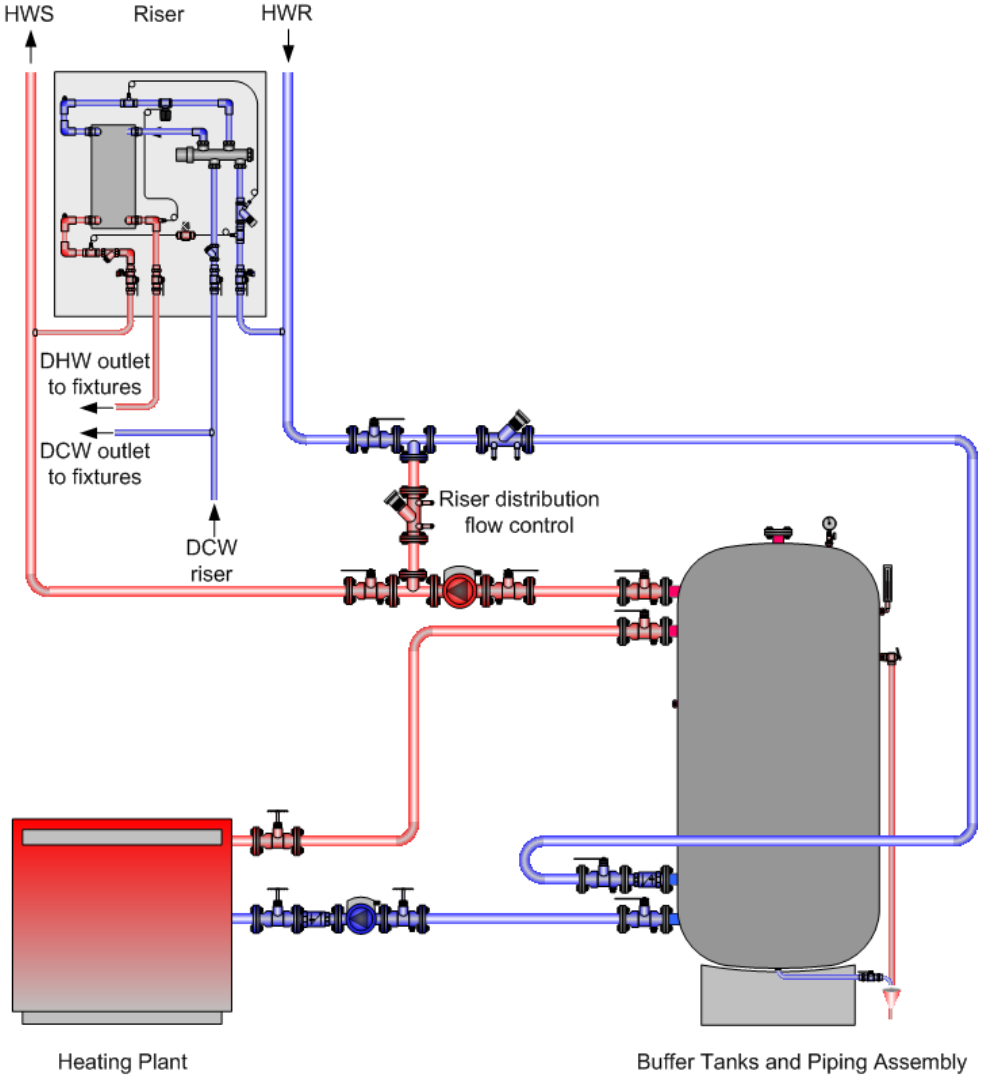
Typical Risers



Typical Riser Dimensioned

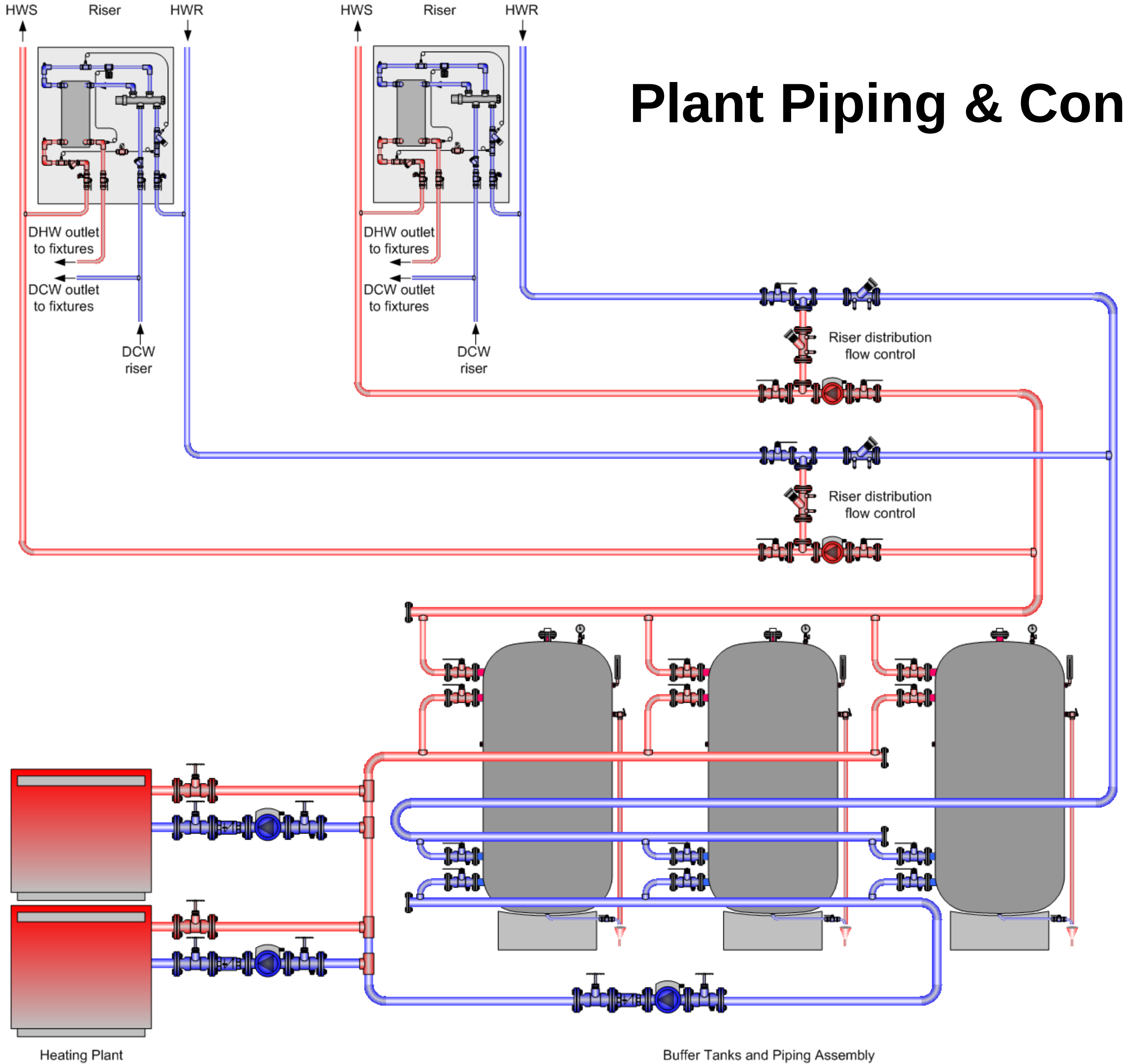


Simplified Plant Piping & Control Representation



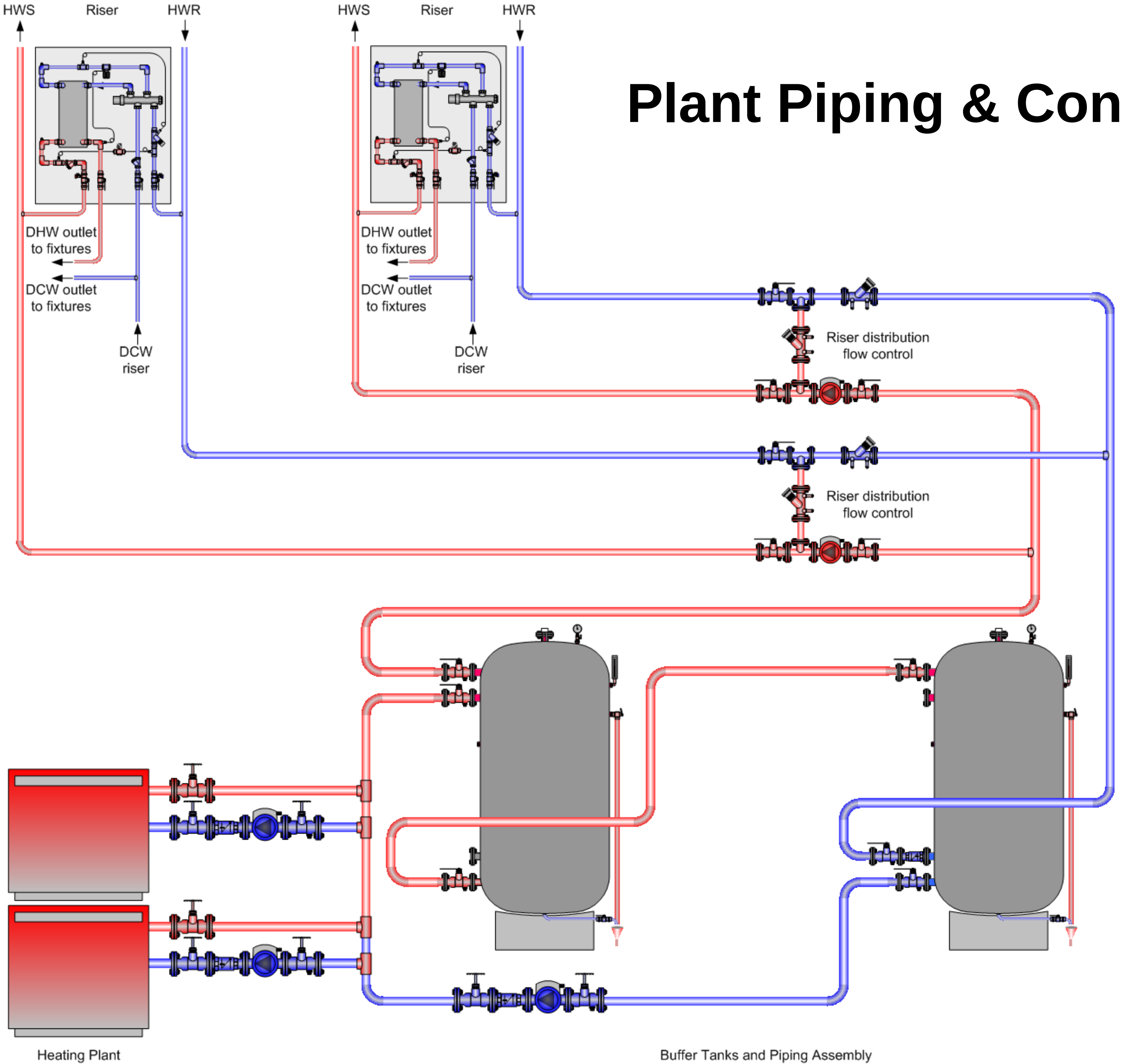
Single-source heating plant with a buffer tank feeding distribution network to system risers.

Plant Piping & Control Representation



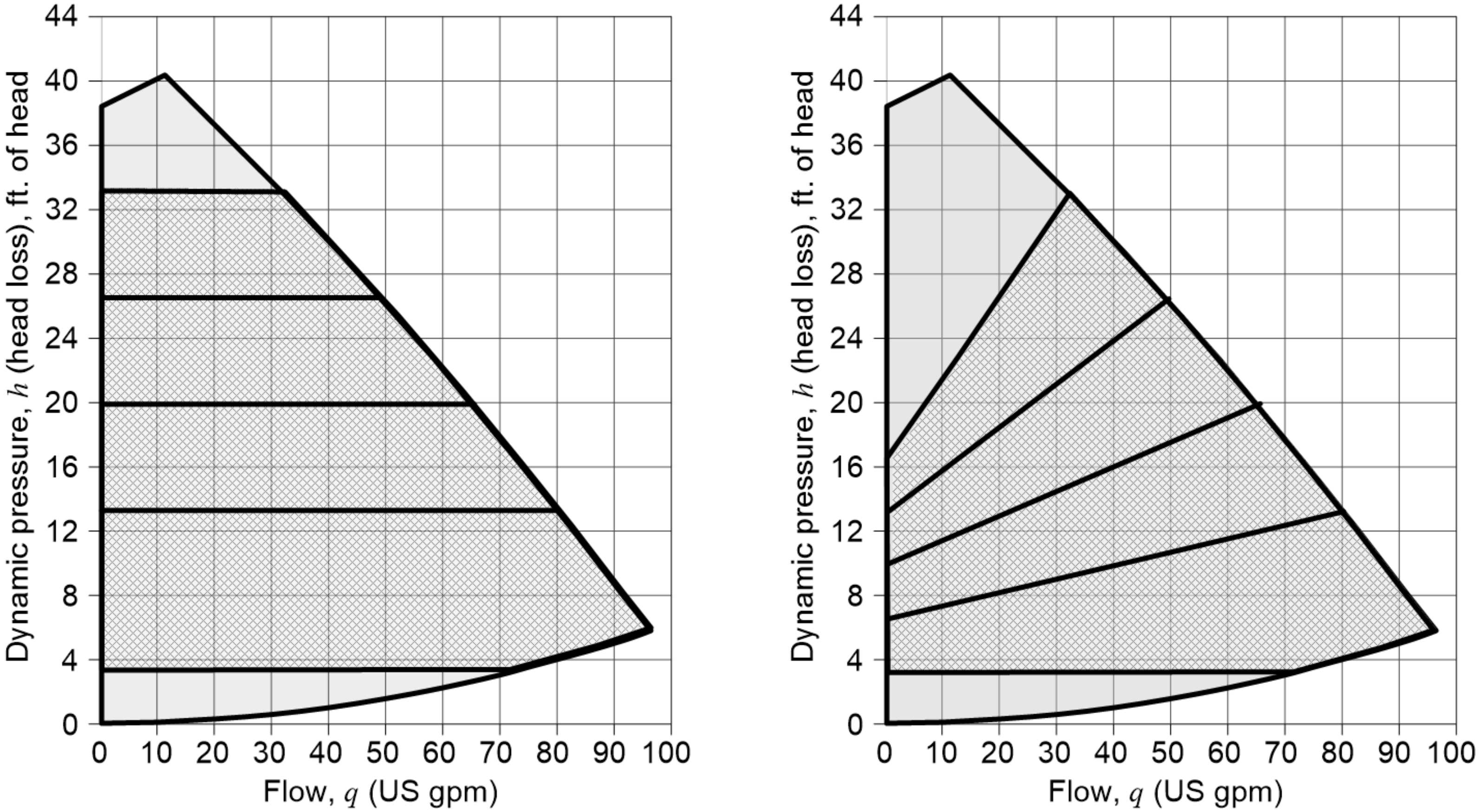
Multisource heating plant using a primary/secondary strategy serving multiple buffer tanks piped in reverse-return, feeding distribution networks to system risers. Generally, parallel buffer tanks are used with systems having more than 200 substations.

Plant Piping & Control Representation



Multisource heating plant using a primary/secondary strategy serving multiple buffer tanks piped in series, feeding distribution networks to system risers. Generally, in-series buffer tanks are used with systems having less than 200 substations.

Flow/pressure…constant or proportional…it depends



It may be necessary, in some cases, to have an external input to the circulator from the system controller to offset (shift) the curves to accommodate peak and seasonal demands through the substations and heat terminal units.

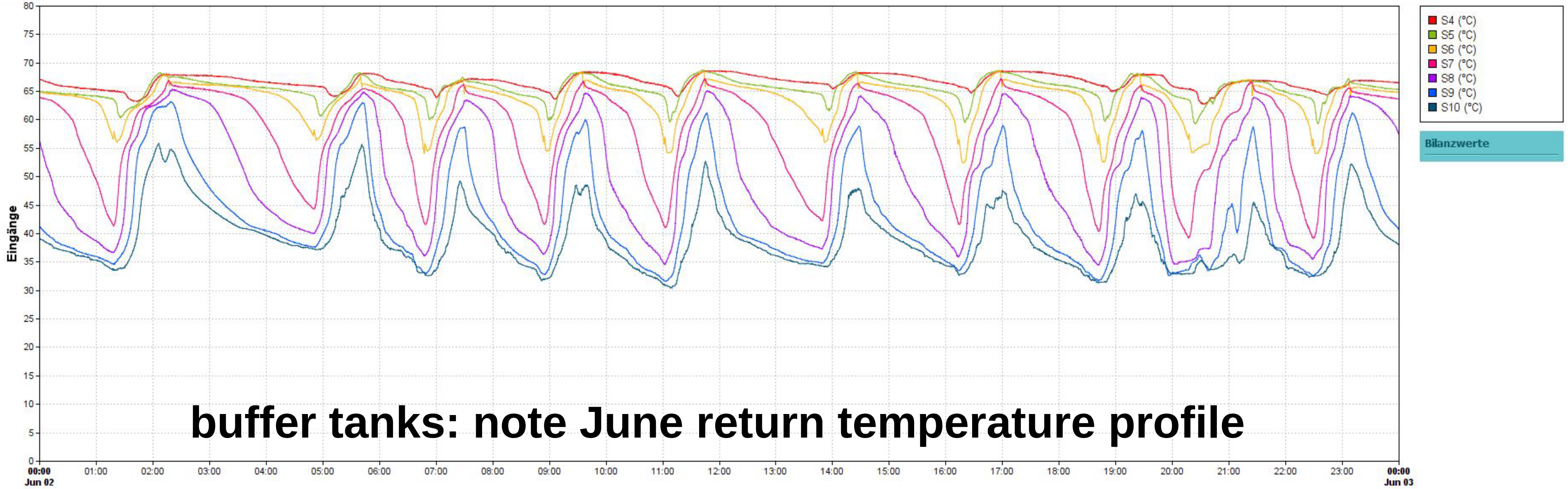
Case Studies

Galileo Business Hotel Marriott Courtyard, Garching bei Muenchen, Germany

256 rooms and 159 apartments, potable demand for hygienic, fast reaction times (5 to 8 seconds), riser supply temperature of 131°F (55°C), high simultaneity of 5 U.S. gpm (19 l/min).

Leonardo Hotel, Dortmund, Germany

181 rooms, potable demand for hygienic, fast reaction times (4 to 6 seconds), riser supply temperature of 140°F (60°C), high simultaneity of 3 U.S. gpm (12 l/min).


buffer tanks: note June return temperature profile
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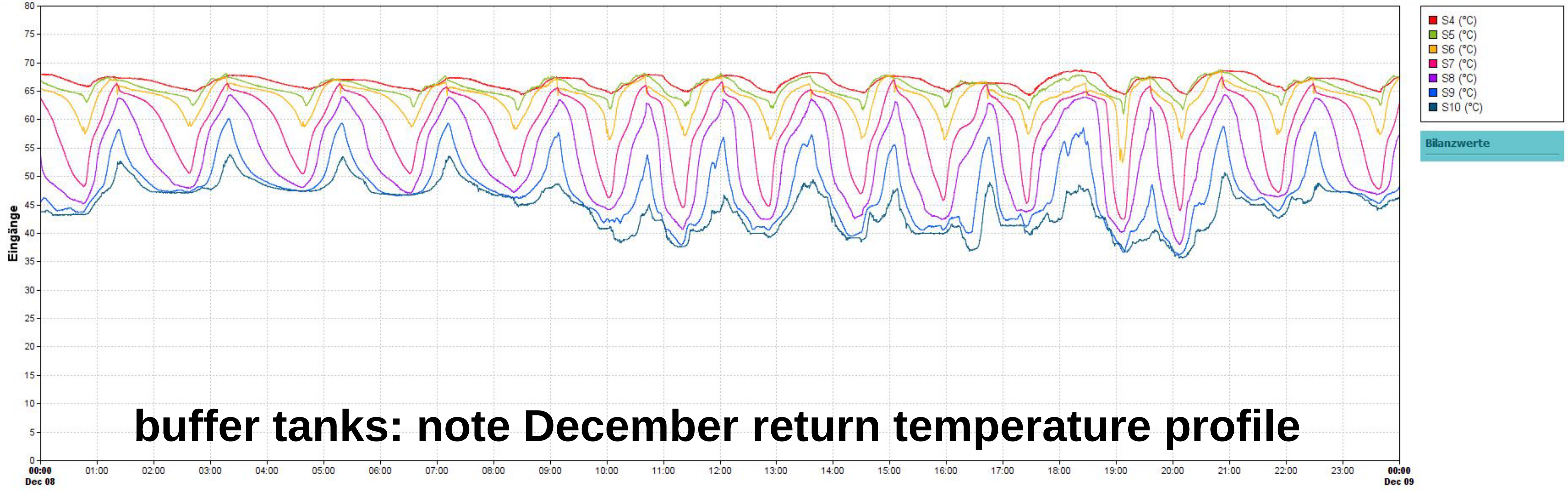
Bilanzwerte


buffer tanks: note December return temperature profile
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Bilanzwerte

Galileo Business Hotel Marriott Courtyard, Garching bei Muenchen, Germany

Leonardo Hotel, Dortmund, Germany

Lessons Learned

Using district energy principles its possible to reduce energy storage & bacteria in domestic piping systems with installed costs on par with traditional systems with improvements in energy and exergy efficiency while preparing the building for future district energy connections and/or decarbonized solutions.

Questions?

Thank you!

Robert Bean

iCCinc

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uponor