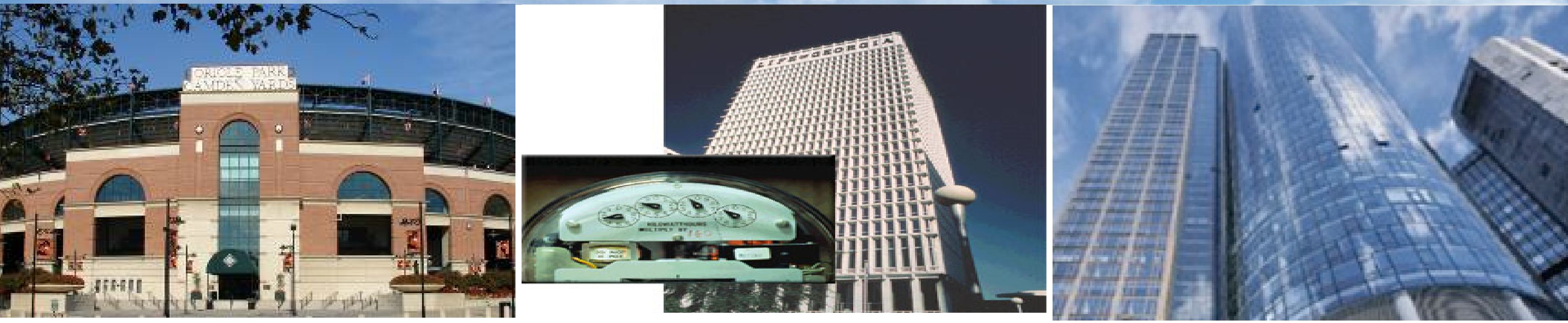
Total Cost of Ownership
Chilled Water Systems

April 17, 2008



Todd Brown

Business Development Manager - Chillers

AGENDA

- Low Flow
- Primary-Secondary vs Variable Primary Flow
- Chillers in Series-Series Counterflow
- Chiller-Tower Optimization

Optimizing Chilled Water Performance

Goal:

Minimize Capital & Operating Costs

Without Sacrificing:

R*eliability, Efficiency, & Comfort*

High Performance Chilled Water Systems:

- **Good for Business...**
  - **Offers lower first cost and lower operating cost.**
- **Good for the Environment:**
  - **Reduced utility generated greenhouse gas emissions.**

Example: Low Flow/ High Delta T

Base Design: 450 Tons

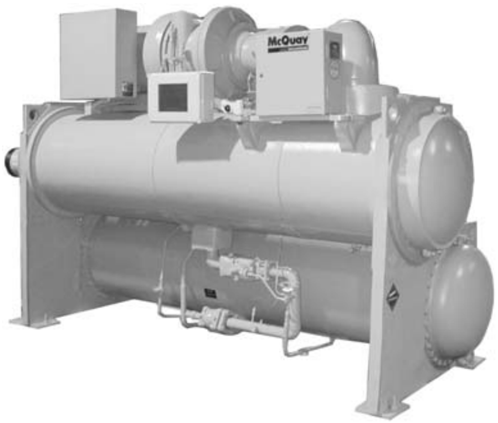
- Design wet bulb: 78 F(25.5C)
- Entering condenser water temperature (ECWT): 85 F(29.4C)
- Evaporator and condenser temperature differences: 10 F (5.6C)
- Coil, valve and chilled water piping pressure drop: 80 ft
- Condenser water piping pressure drop: 30 ft
- Pump efficiency: 75%
- Pump motor efficiency: 93%

ASSUMPTIONS

Chiller (2.4, 3.0 gpm/ton)

- **Consumption:**
  256 kW (0.569 kW/ton)
- **Evaporator pressure drop: 21.0 ft**
- **Condenser pressure drop: 21.3 ft**

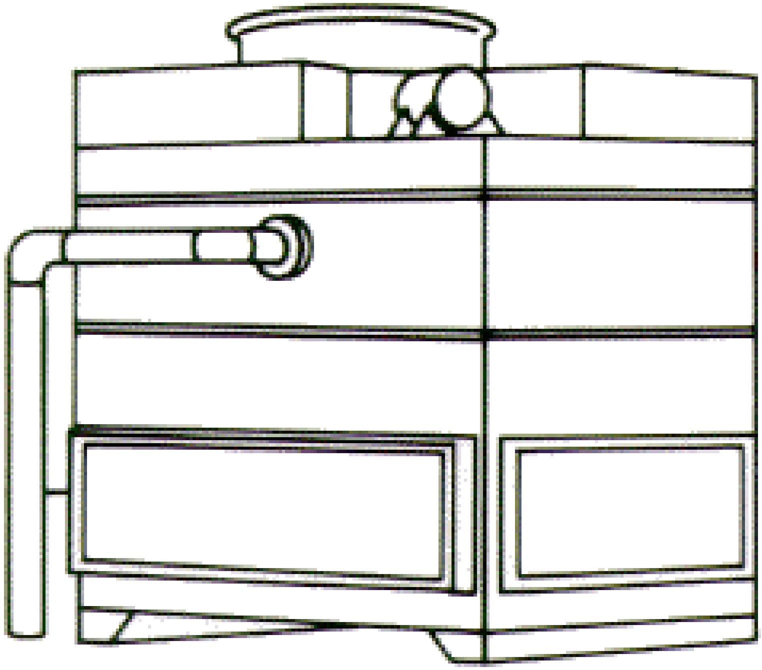
Base
10°F ΔT



Cooling Tower (3.0 gpm/ton)

Base
10°F ΔT

- **Power rating:**
  30 hp
- **Tower static head:**
  10.0 ft



Design Formulas

$$\text{hp} = \frac{\text{gpm x PD}}{\text{3960 x pump efficiency}}$$

$$\text{kW} = \frac{\text{0.746 x hp}}{\text{motor efficiency}}$$

$$\text{DP2/DP1} = (\text{Flow2/Flow1})^{1.85}$$

gpm œ rpm

Head œ $(\text{gpm})^2$

Power œ $(\text{gpm})^3$

ASSUMPTIONS

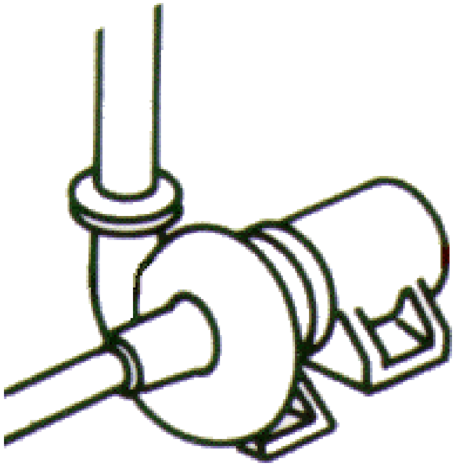
example chilled water plant …

Chilled Water Pump (2.4 gpm/ton)

Base
10°F ΔT

- **System conditions …**
  - **System head: 80 ft**
  - **Bundle head: 21.0 ft**
  - **Flow rate: 1080 gpm**

- **Pump power …**
  - **36.7 hp**
  - **29.5 kW**

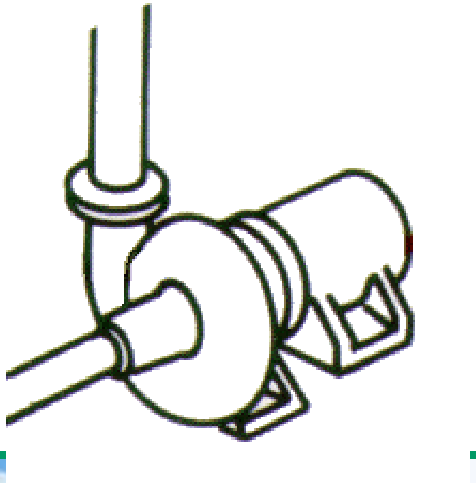


example chilled water plant …

Condenser Water Pump (3.0 gpm/ton)

Base
10°F ΔT

- **System conditions …**
  - **System head: 26.0 ft**
  - **Bundle head: 21.3 ft**
  - **Tower static: 10.0 ft**
  - **Flow rate: 1350 gpm**
- **Pump power …**
  - **26.0 hp**
  - **20.8 kW**

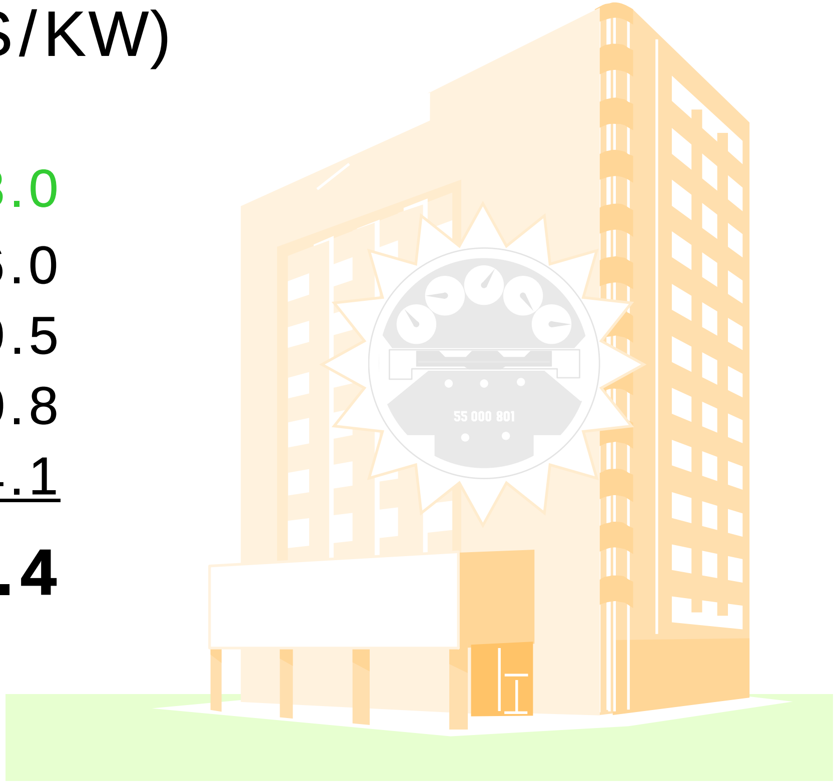


example chilled water plant …

System Energy Consumption

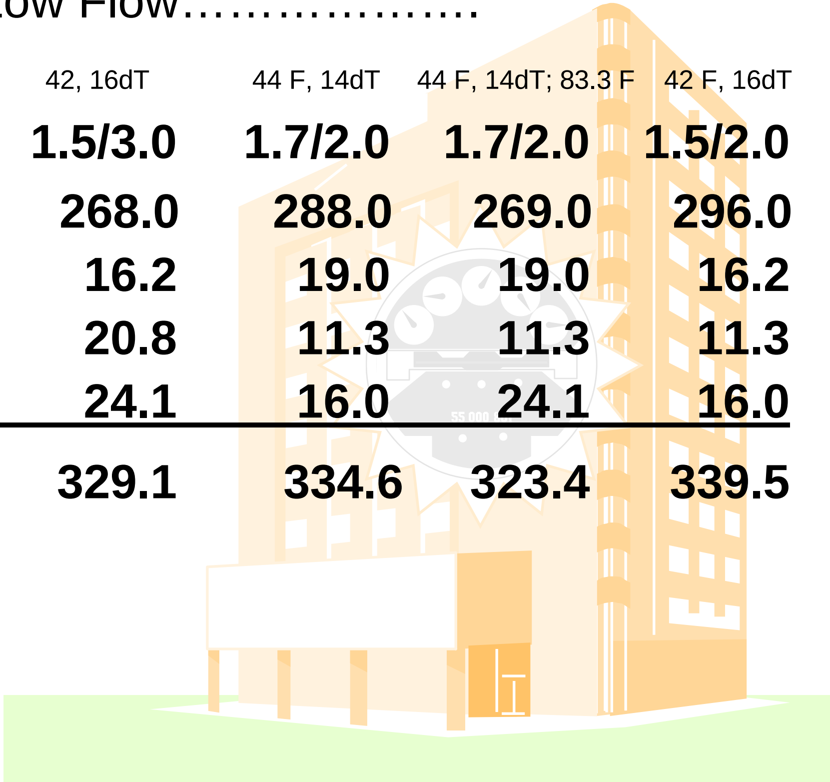
- With 2.4, 3.0 gpm/ton flows …
  (0.043, 0.054 L/S/KW)

	2.4/3.0
Chiller	256.0
Chilled Water Pump	29.5
Condenser Water Pump	20.8
Cooling Tower	24.1
Total kW	**330.4**



example chilled water plant …

Low Flow System



	Base Case	Low Flow……………….			
	ARI	42, 16dT	44 F, 14dT	44 F, 14dT; 83.3 F	42 F, 16dT
	2.4/3.0	**1.5/3.0**	**1.7/2.0**	**1.7/2.0**	**1.5/2.0**
Chiller	**256.0**	**268.0**	**288.0**	**269.0**	**296.0**
Chilled Water Pump	**29.5**	**16.2**	**19.0**	**19.0**	**16.2**
Condenser Water Pump	**20.8**	**20.8**	**11.3**	**11.3**	**11.3**
Cooling Tower	**24.1**	**24.1**	**16.0**	**24.1**	**16.0**
Total kW	**330.4**	**329.1**	**334.6**	**323.4**	**339.5**

What About Part Load Operation?

We'll use …

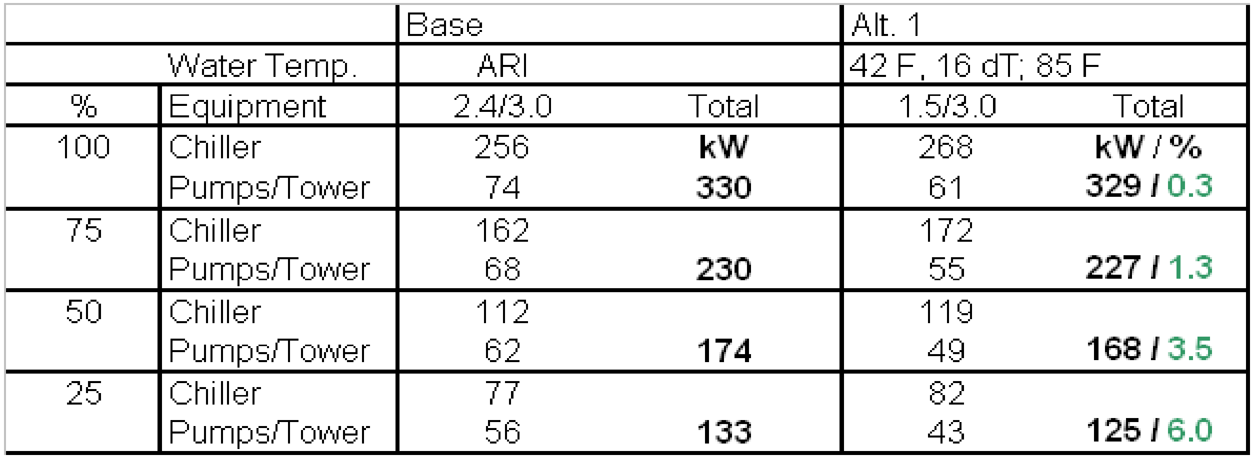
- Chiller kW values for NPLV
  - Derived from the selection program
- Cooling tower kW
  - Tower energy at part load based on being linear with speed reduction

And constant kW values for the …

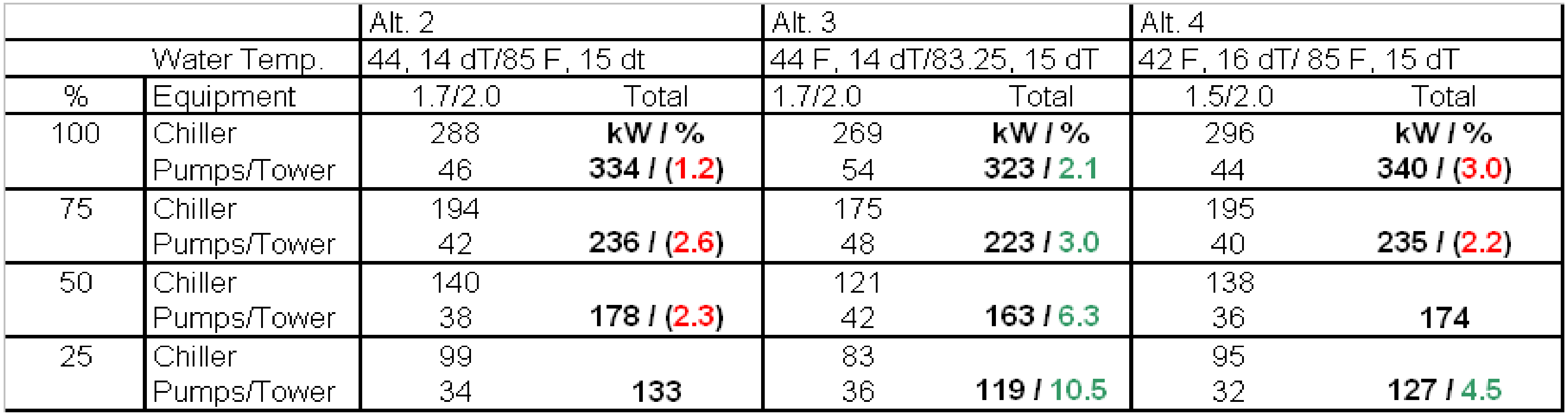
- Chilled water pump
- Condenser water pump

ASSUMPTIONS

Part Load Operation



		Base		Alt. 1	
	Water Temp.	ARI		42 F, 16 dT; 85 F	
%	Equipment	2.4/3.0	Total	1.5/3.0	Total
100	Chiller	256	**kW**	268	**kW / %**
	Pumps/Tower	74	**330**	61	**329 / 0.3**
75	Chiller	162		172	
	Pumps/Tower	68	**230**	55	**227 / 1.3**
50	Chiller	112		119	
	Pumps/Tower	62	**174**	49	**168 / 3.5**
25	Chiller	77		82	
	Pumps/Tower	56	**133**	43	**125 / 6.0**



		Alt. 2		Alt. 3		Alt. 4	
	Water Temp.	44, 14 dT/85 F, 15 dt		44 F, 14 dT/83.25, 15 dT		42 F, 16 dT/ 85 F, 15 dT	
%	Equipment	1.7/2.0	Total	1.7/2.0	Total	1.5/2.0	Total
100	Chiller	288	**kW / %**	269	**kW / %**	296	**kW / %**
	Pumps/Tower	46	**334 / (1.2)**	54	**323 / 2.1**	44	**340 / (3.0)**
75	Chiller	194		175		195	
	Pumps/Tower	42	**236 / (2.6)**	48	**223 / 3.0**	40	**235 / (2.2)**
50	Chiller	140		121		138	
	Pumps/Tower	38	**178 / (2.3)**	42	**163 / 6.3**	36	**174**
25	Chiller	99		83		95	
	Pumps/Tower	34	**133**	36	**119 / 10.5**	32	**127 / 4.5**

you’ve got more …

System Design Options

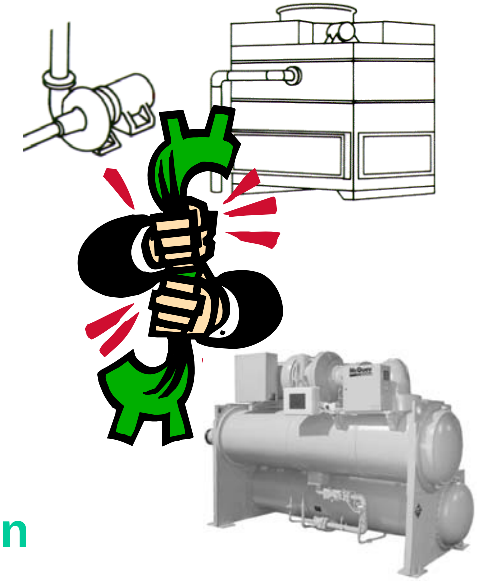
Either …

- Take full energy (operating cost) savings

Or …

- Reduce piping size and cost

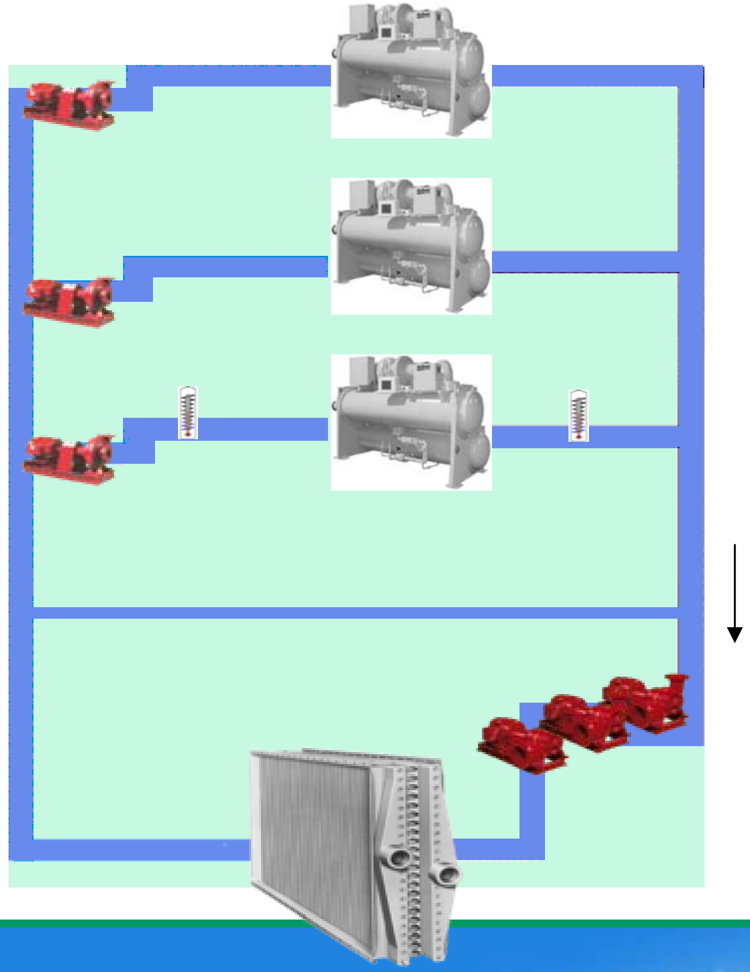
Experienced designers use pump, piping and tower savings to select an even more efficient chiller

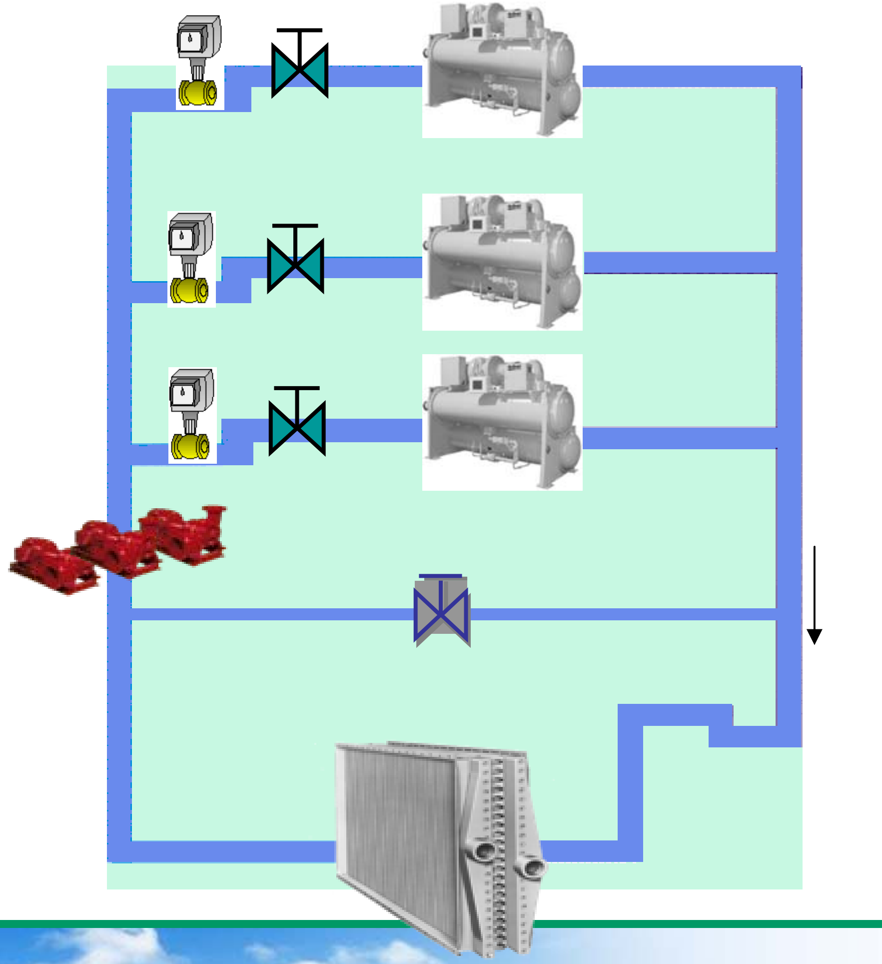


Decoupled Systems

moving to…

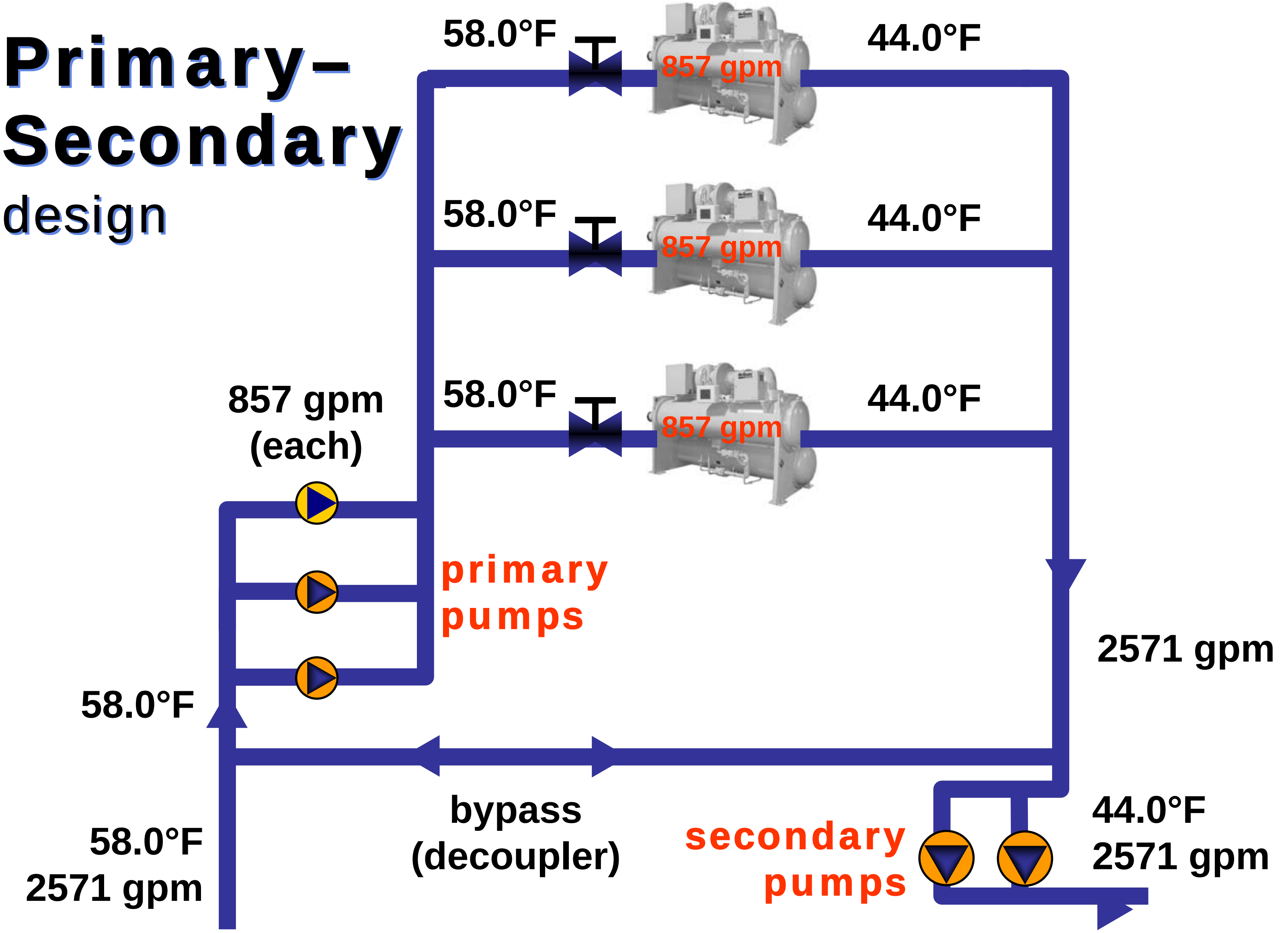
Variable Flow Systems



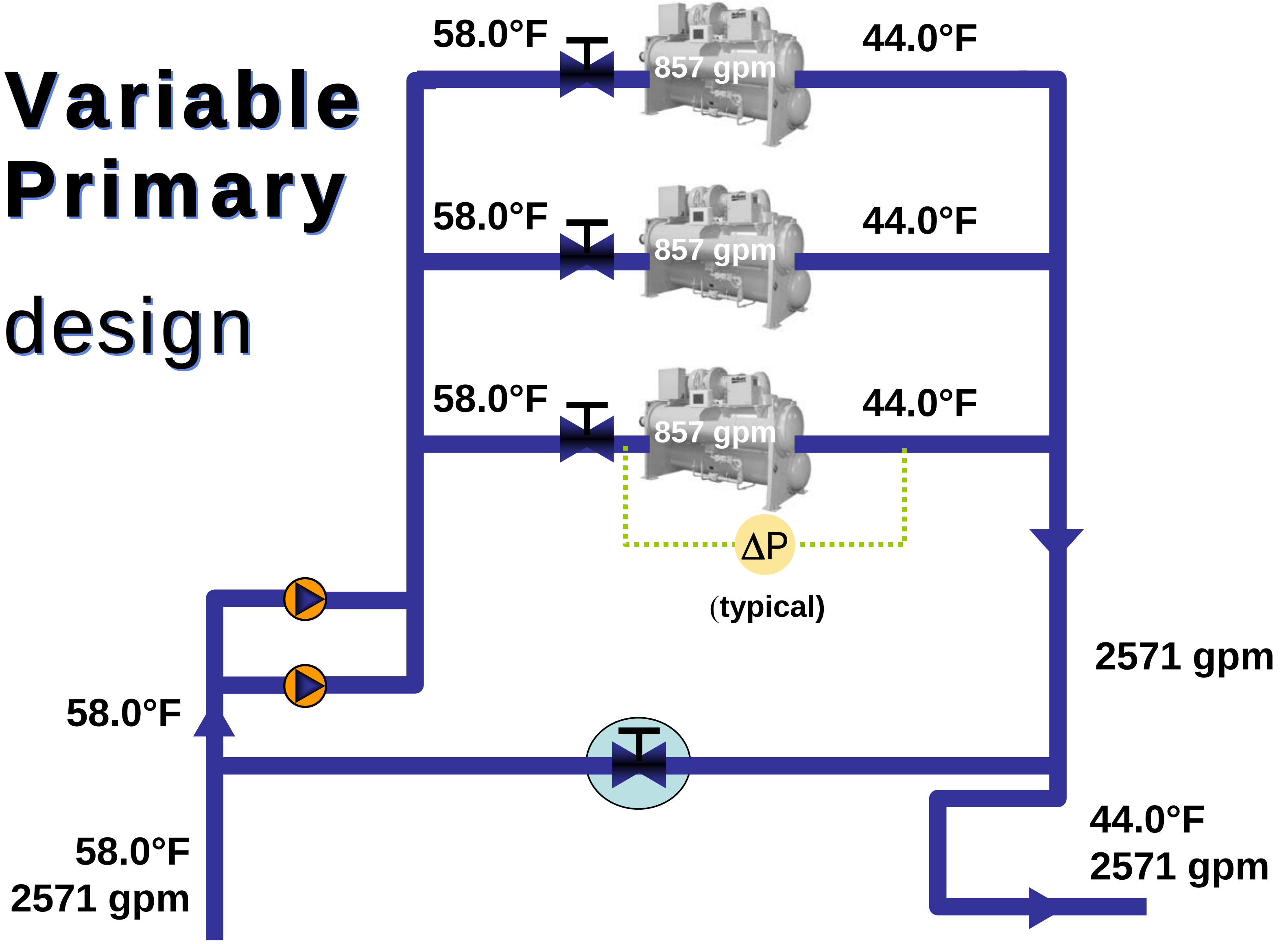


Primary–Secondary

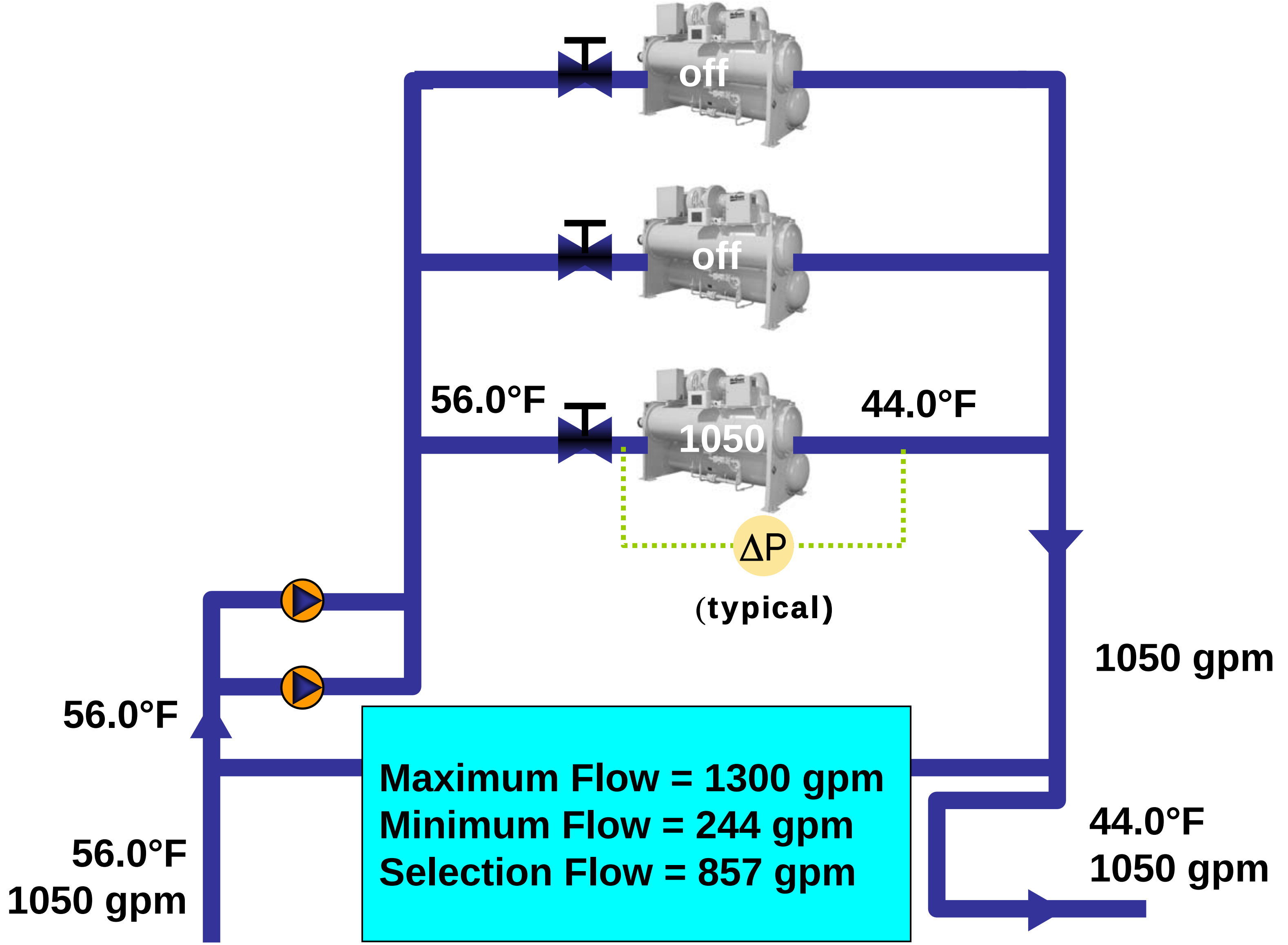
design



Variable Primary design

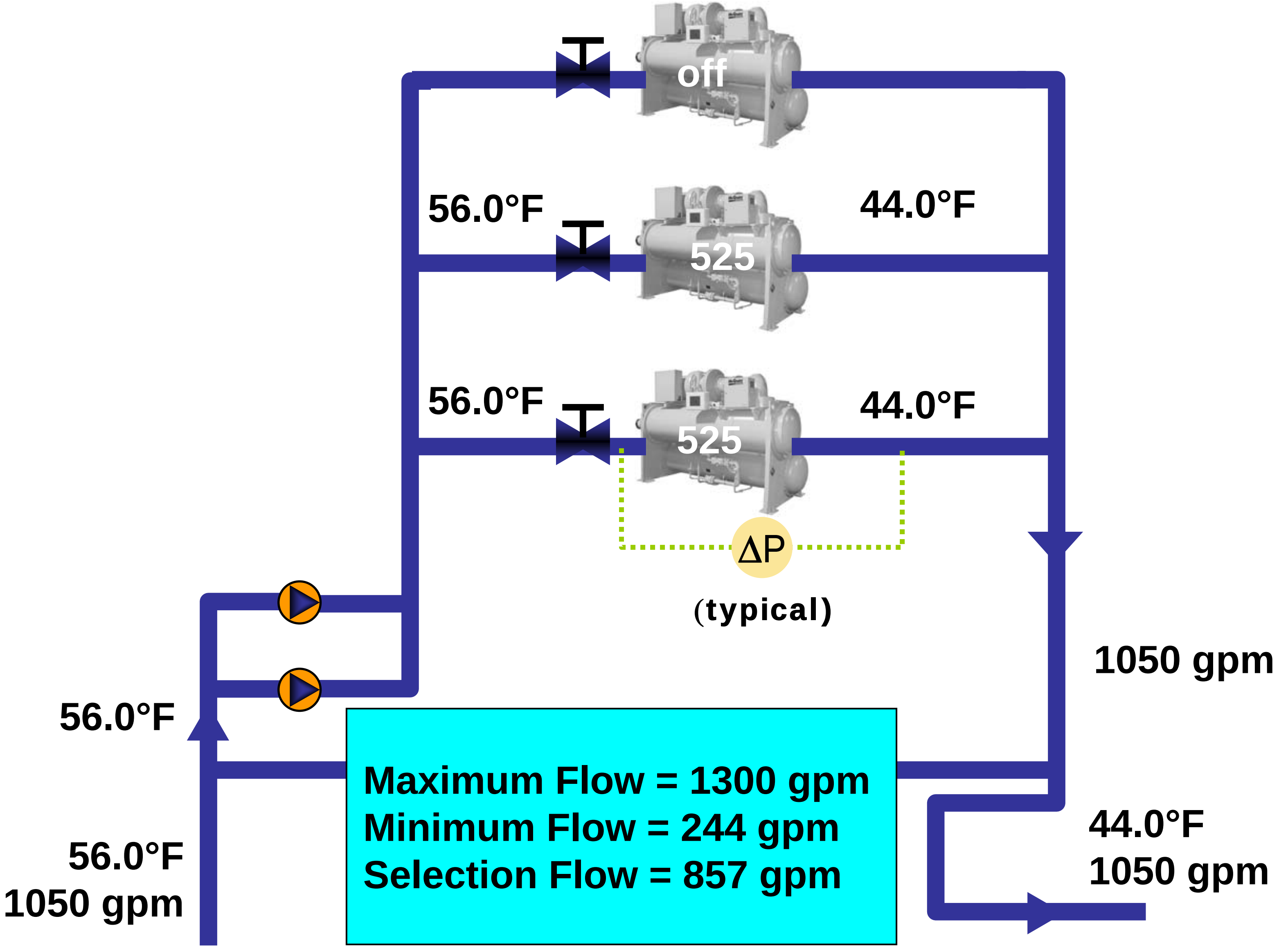


Variable Primary part load



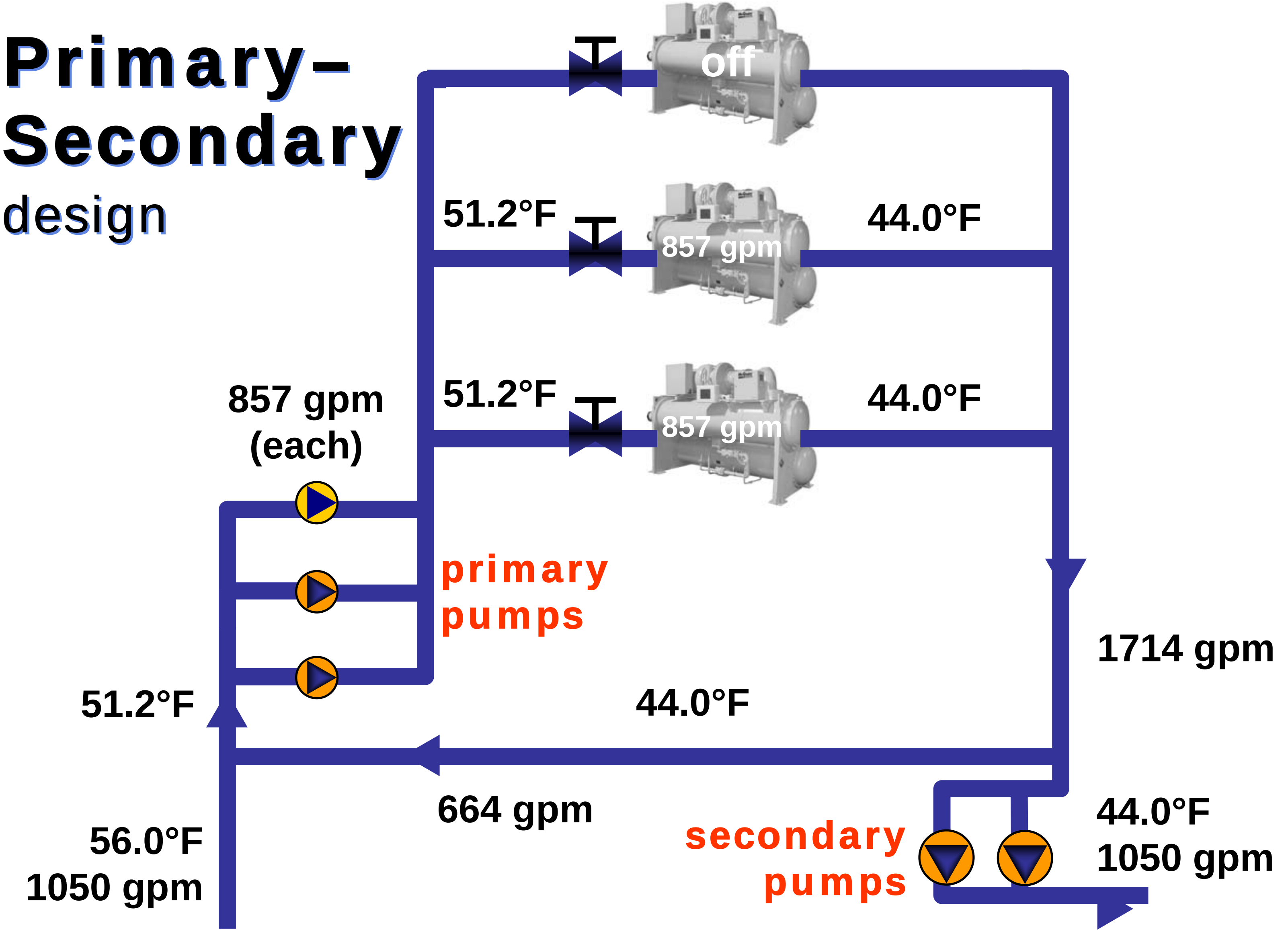
Maximum Flow = 1300 gpm
Minimum Flow = 244 gpm
Selection Flow = 857 gpm

Variable Primary part load



Maximum Flow = 1300 gpm
Minimum Flow = 244 gpm
Selection Flow = 857 gpm

Primary–Secondary design



Lower Capital Cost Variable Primary advantages

- Fewer …
  - Pumps
  - Motors
  - Pump bases
  - Starters and wiring
  - Fittings and piping
  - Controls
- Less labor

More Available Space

Opportunity to …

- Add other equipment
- Select larger, more efficient chillers
- Improve service access

Simplified Control

- Unfetters chillers from flow-based control
- Operates distribution pumps to transport water

  … not to start/stop chillers

Improved Reliability

Provides system with …

- Fewer pumps and accessories
- Fewer chiller recovery options
- Fewer pump recovery options
- Better balance between pumps and chillers online

Chiller Selection Considerations

- Evaporator flow limits
- Rate-of-change tolerance
- Flow “range-ability”
  - Difference between selection flow rate and evaporator minimum flow limit

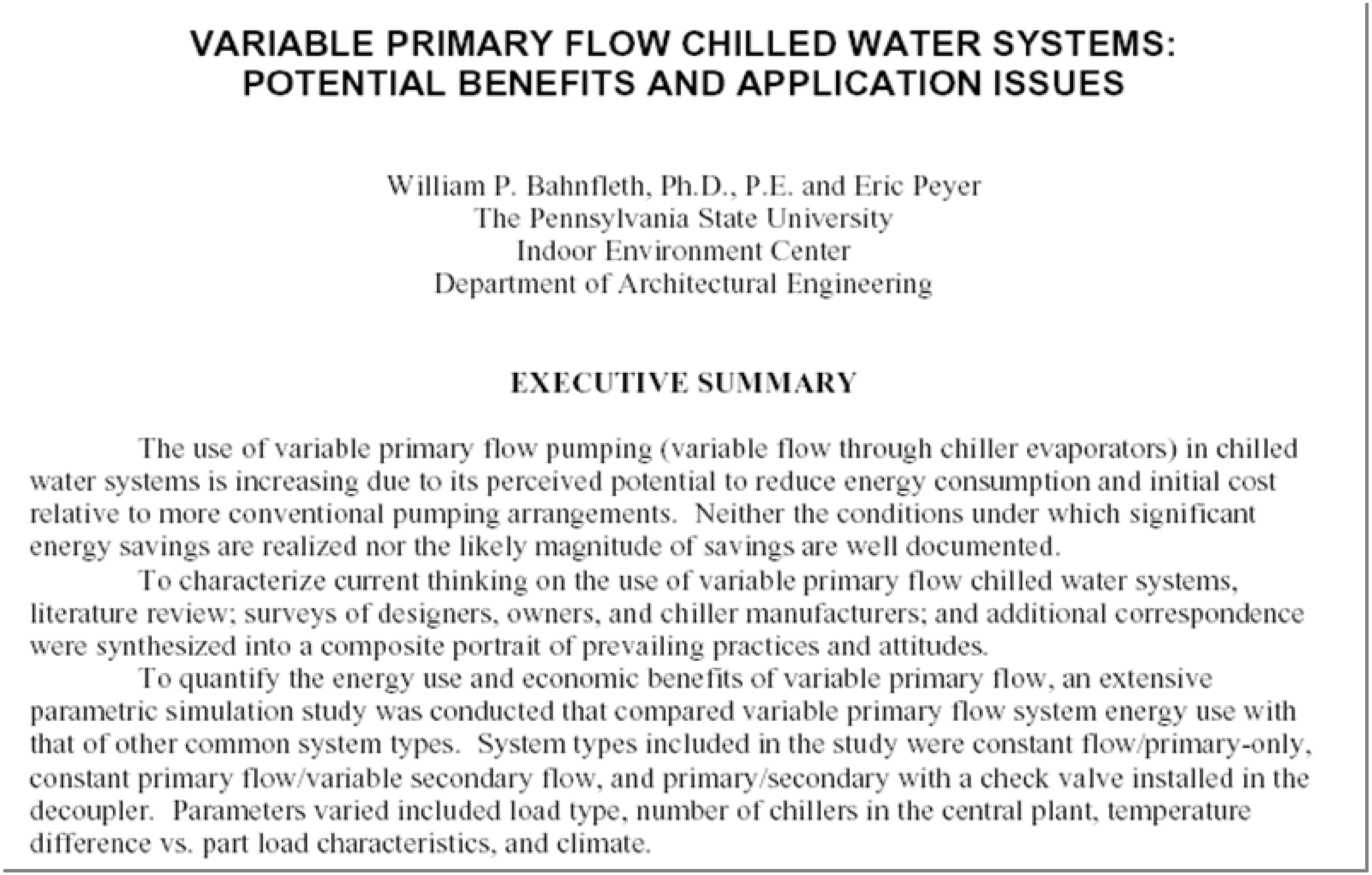
What are other's saying???

Variable Primary Flow Chilled Water Plant Design …

HVAC&R Research for the 21st Century – "an ARI Research Initiative"

Air-Conditioning & Refrigeration Technology Institute (ARTI)

4100 North Fairfax Drive, Suite 200, Arlington, Virginia 22203 Phone: 703.524.8800 Fax: 703.522.2349



VARIABLE PRIMARY FLOW CHILLED WATER SYSTEMS: POTENTIAL BENEFITS AND APPLICATION ISSUES

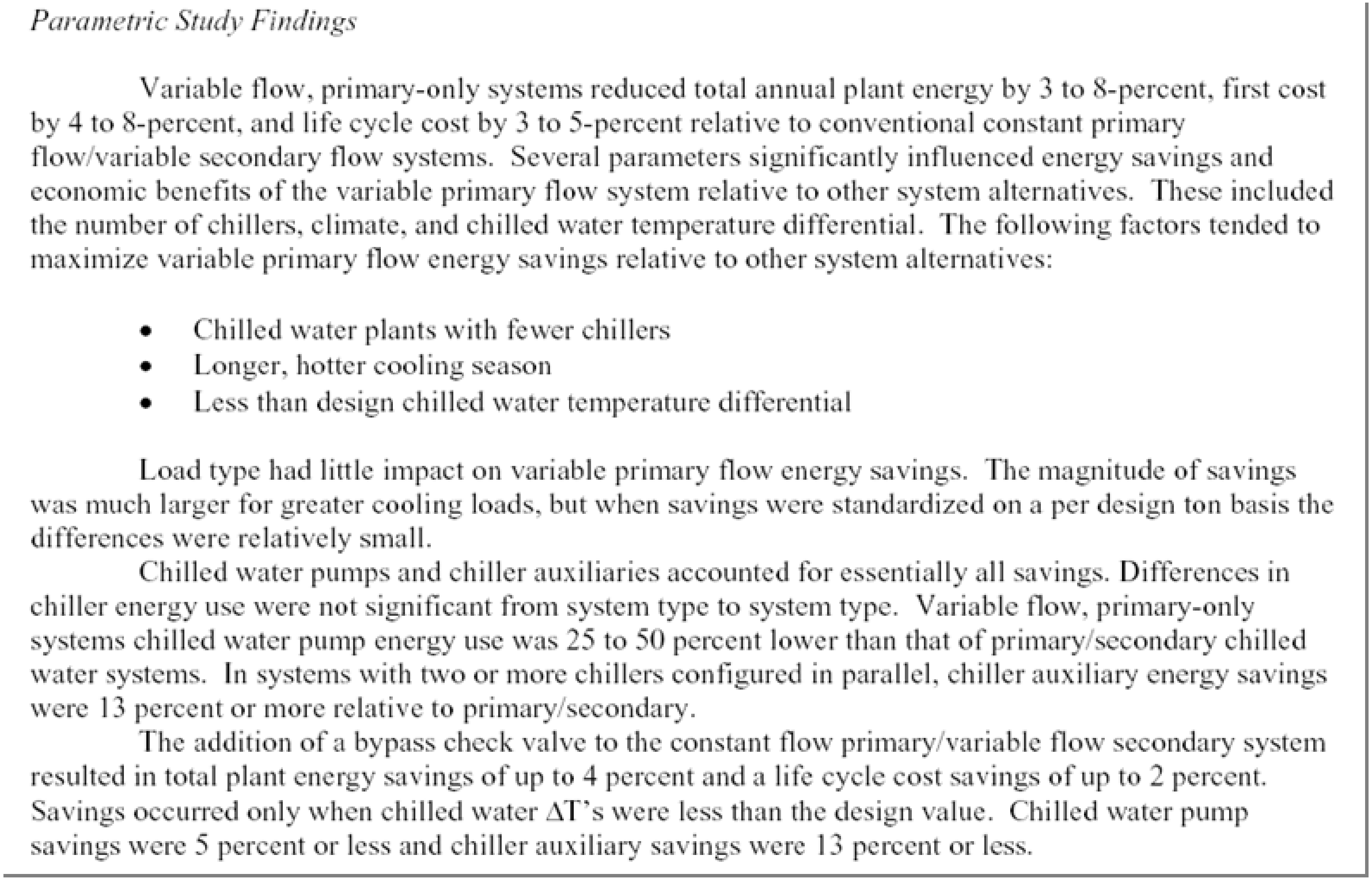
William P. Bahnfleth, Ph.D., P.E. and Eric Peyer
The Pennsylvania State University
Indoor Environment Center
Department of Architectural Engineering

EXECUTIVE SUMMARY

The use of variable primary flow pumping (variable flow through chiller evaporators) in chilled water systems is increasing due to its perceived potential to reduce energy consumption and initial cost relative to more conventional pumping arrangements. Neither the conditions under which significant energy savings are realized nor the likely magnitude of savings are well documented.

To characterize current thinking on the use of variable primary flow chilled water systems, literature review; surveys of designers, owners, and chiller manufacturers; and additional correspondence were synthesized into a composite portrait of prevailing practices and attitudes.

To quantify the energy use and economic benefits of variable primary flow, an extensive parametric simulation study was conducted that compared variable primary flow system energy use with that of other common system types. System types included in the study were constant flow/primary-only, constant primary flow/variable secondary flow, and primary/secondary with a check valve installed in the decoupler. Parameters varied included load type, number of chillers in the central plant, temperature difference vs. part load characteristics, and climate.



Parametric Study Findings

Variable flow, primary-only systems reduced total annual plant energy by 3 to 8-percent, first cost by 4 to 8-percent, and life cycle cost by 3 to 5-percent relative to conventional constant primary flow/variable secondary flow systems. Several parameters significantly influenced energy savings and economic benefits of the variable primary flow system relative to other system alternatives. These included the number of chillers, climate, and chilled water temperature differential. The following factors tended to maximize variable primary flow energy savings relative to other system alternatives:

- Chilled water plants with fewer chillers
- Longer, hotter cooling season
- Less than design chilled water temperature differential

Load type had little impact on variable primary flow energy savings. The magnitude of savings was much larger for greater cooling loads, but when savings were standardized on a per design ton basis the differences were relatively small.

Chilled water pumps and chiller auxiliaries accounted for essentially all savings. Differences in chiller energy use were not significant from system type to system type. Variable flow, primary-only systems chilled water pump energy use was 25 to 50 percent lower than that of primary/secondary chilled water systems. In systems with two or more chillers configured in parallel, chiller auxiliary energy savings were 13 percent or more relative to primary/secondary.

The addition of a bypass check valve to the constant flow primary/variable flow secondary system resulted in total plant energy savings of up to 4 percent and a life cycle cost savings of up to 2 percent. Savings occurred only when chilled water ΔT's were less than the design value. Chilled water pump savings were 5 percent or less and chiller auxiliary savings were 13 percent or less.

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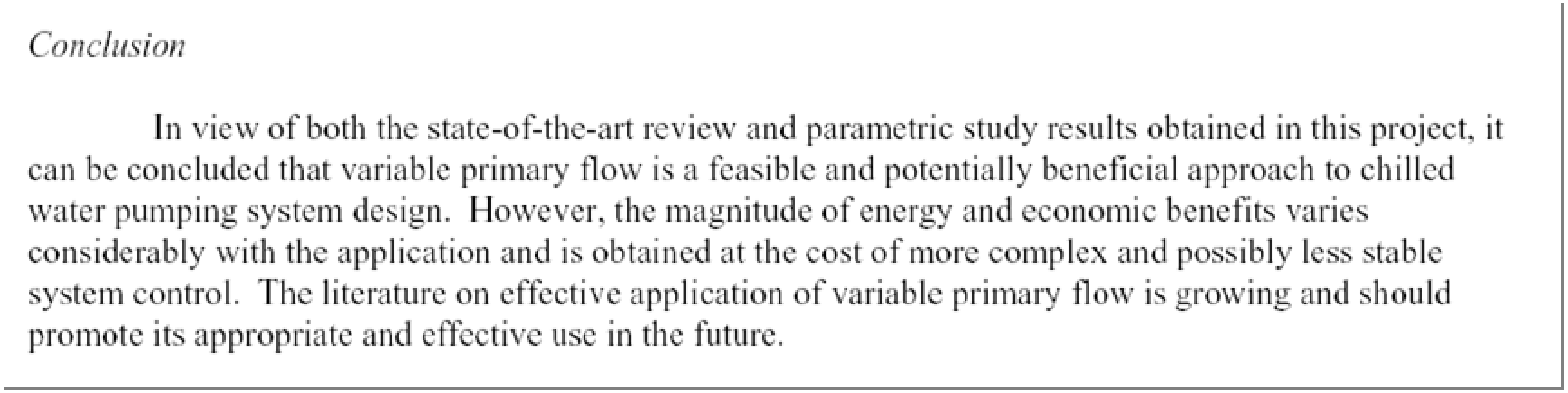
VFP systems:

- **Reduces total annual plant energy 3-8%**
- **Reduces first cost 4-8%**
- **Reduces life-cycle cost 3-5%***

**Relative to conventional Decoupled chilled-water systems.*



Conclusion

In view of both the state-of-the-art review and parametric study results obtained in this project, it can be concluded that variable primary flow is a feasible and potentially beneficial approach to chilled water pumping system design. However, the magnitude of energy and economic benefits varies considerably with the application and is obtained at the cost of more complex and possibly less stable system control. The literature on effective application of variable primary flow is growing and should promote its appropriate and effective use in the future.

VPF System

More information

- “Don’t Ignore Variable Flow,” Waltz, Contracting Business, July 1997
- “Primary-Only vs. Primary-Secondary Variable Flow Systems,” Taylor, ASHRAE Journal, February 2002
- “*Comparative Analysis of Variable and Constant Primary-Flow Chilled-Water-Plant Performance*,” Bahnfleth and Peyer, HPAC Engineering, April 2001
- “*Campus Cooling: Retrofitting Systems*,” Kreutzmann, HPAC Engineering, July 2002

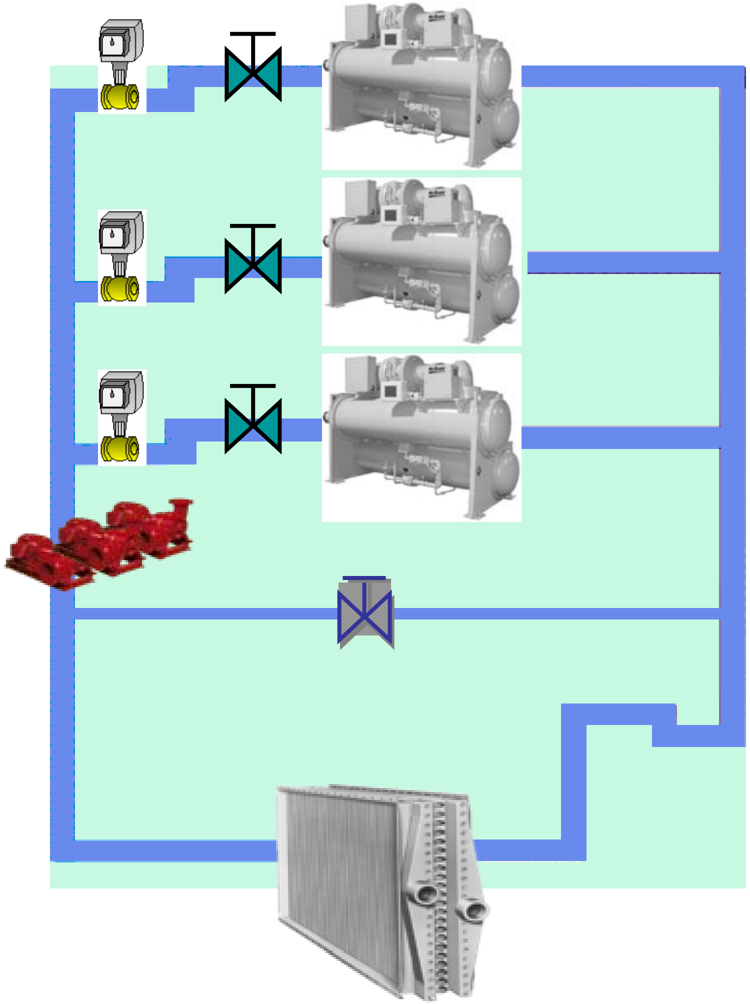
unsuited for

Variable Primary Flow

- Inadequate control capability
  - Insufficient chiller unloading
  - Vintage chiller controls
- Poor financial return

  (Consider chilled water reset instead)

Parallel VPF Systems

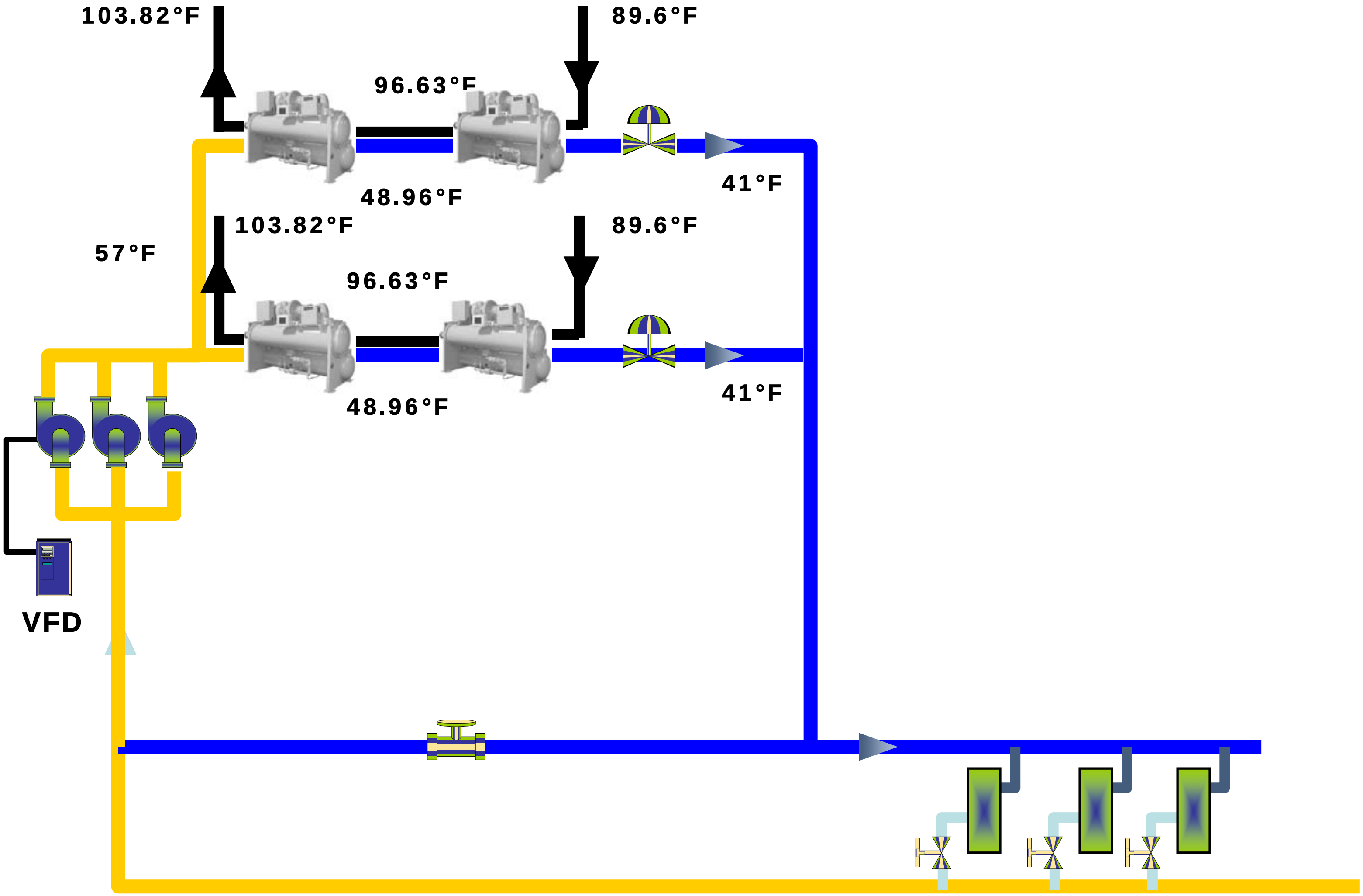


moving to…

Series Evaporator Systems

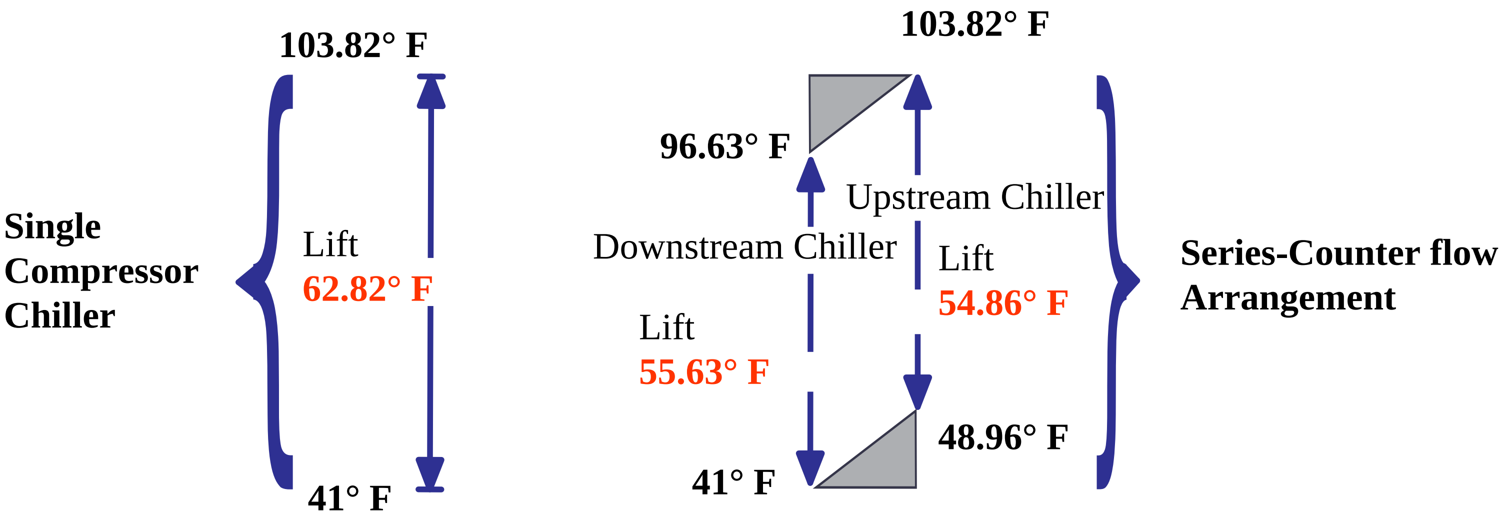
VPF system configurations

Series-Counter Flow



VPF system configurations

Series-Counter Flow



- Upstream chiller: 103.82 - 48.96 = **54.86**
- Downstream chiller: 96.63 - 41 = **55.63**
- Average lift: **55.24**
  (vs. 62.82 for single compressor (**12%**))

Better chiller efficiency, but high ΔP

Chiller–Tower Optimization …

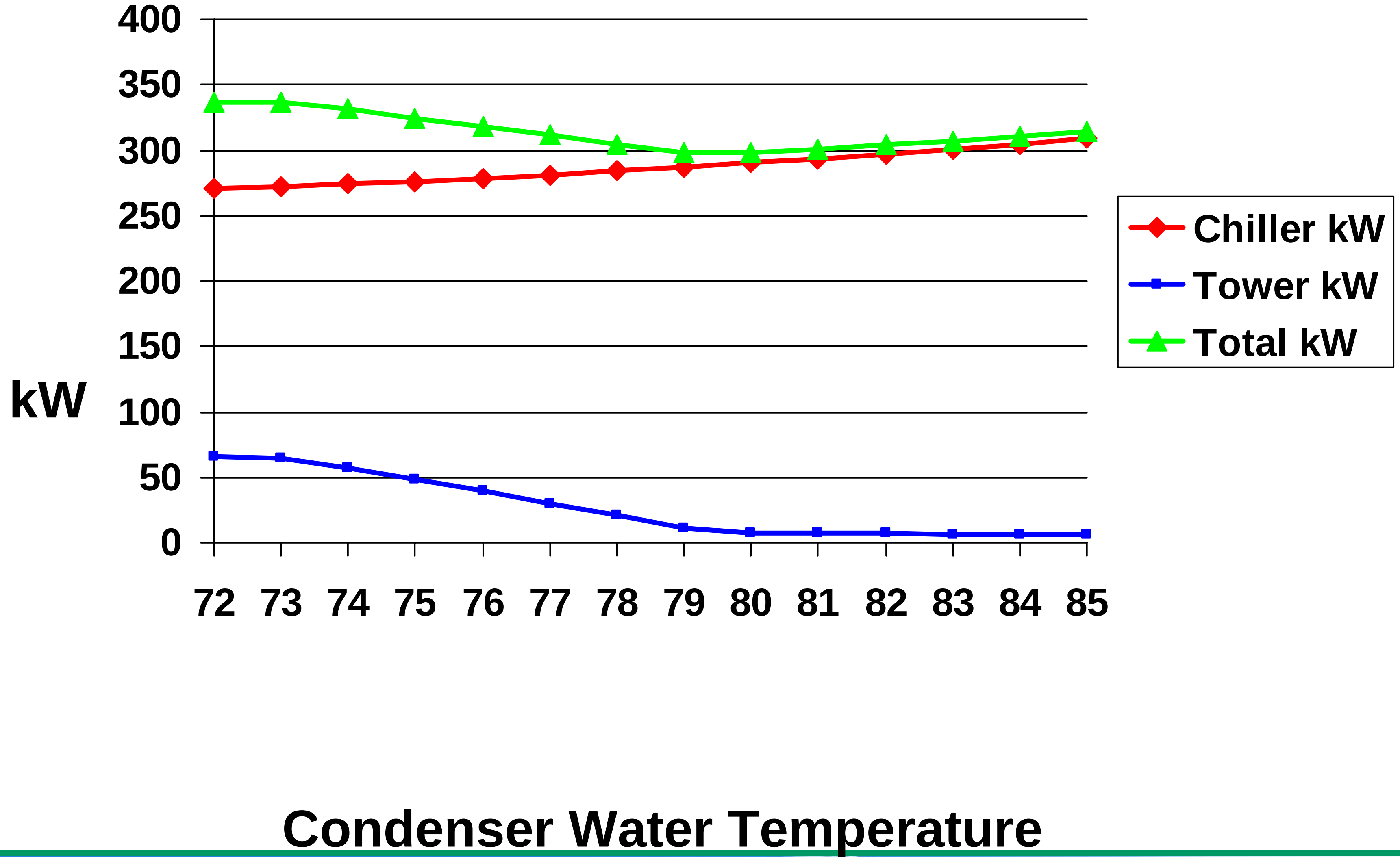
Do It Right!

chiller–tower optimization

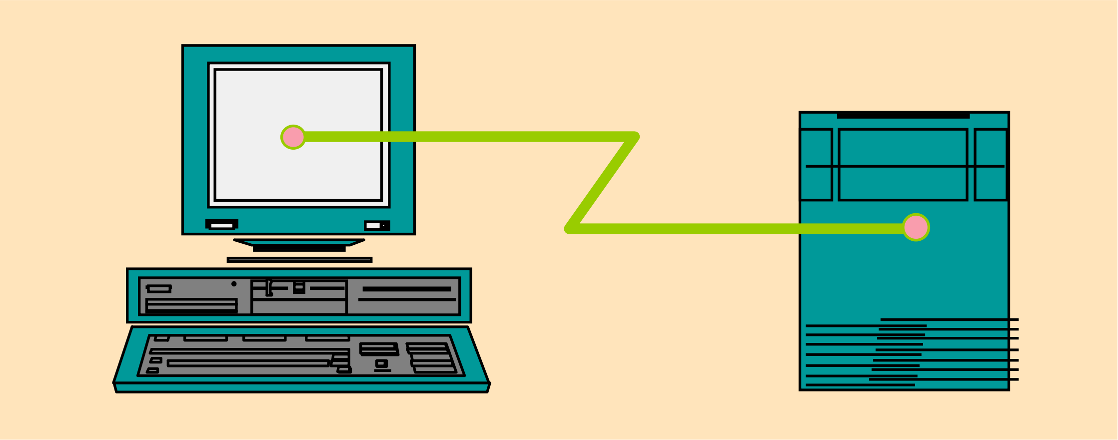
The Question …

- What’s the “right” condenser water temperature?

Or Said Another Way …



How Do You *Do* It?



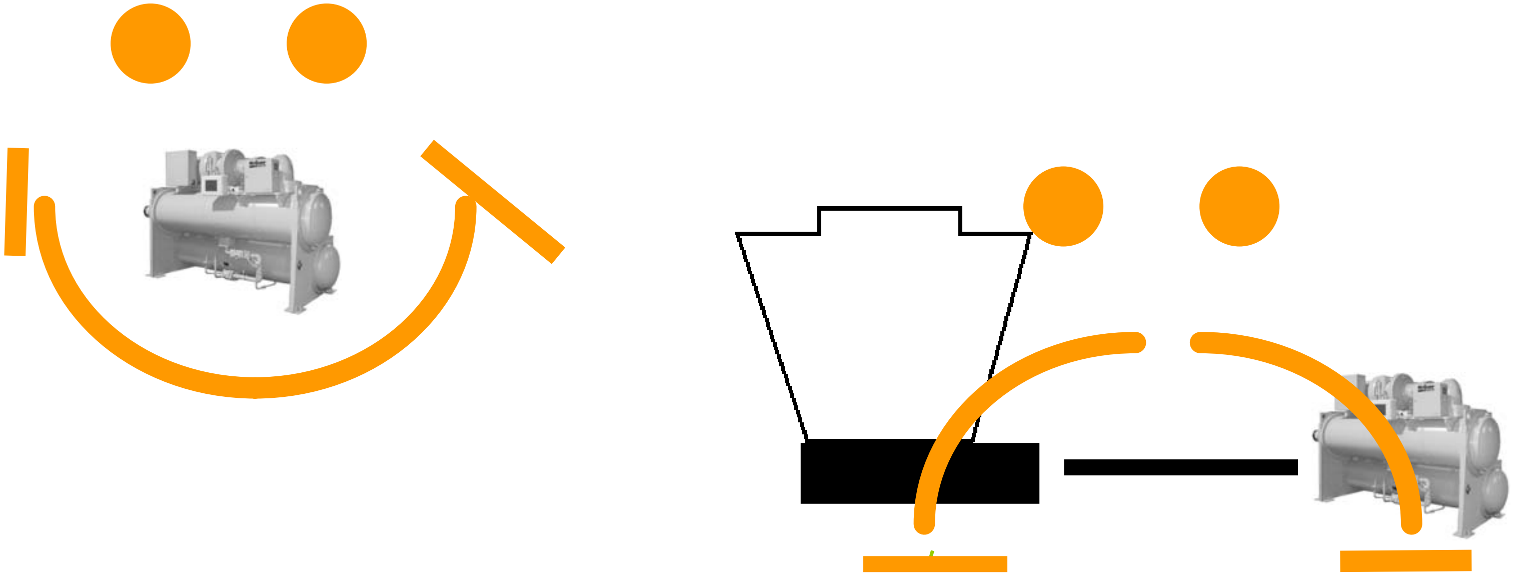
With real-life controls!

How do you do it?

- MicroTech II and BAS Combination

The **optimized method** requires auto-adaptive controls. This control logic constantly adjusts the condenser water supply temperature to the value that uses the least amount of power. The controller measures the power requirement for the chiller and cooling tower. The condenser water temperature setpoint then is altered and the power consumption is checked again. If the total power consumption goes down, a similar adjustment is made and the total power is checked again.

What's good for the component … may NOT be good for the system!



where’s the meter?

The Only Possible Response …

On the building!

In Summary ...

- Defines the optimal entering condenser temperature
- Optimal control is the right thing to do … AND it saves money
- Savings are real and can be quantified
- The control strategy is available NOW!

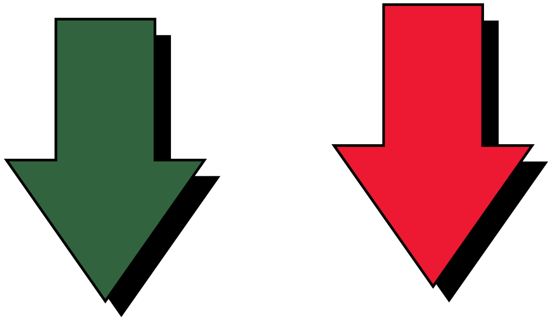
Lowest Total Cost of Ownership

Exploit technology!

- Low flow
- Low temperature
- High efficiency
- Controls

Leverage:

- Optimized Controls
- Variable Primary Flow
- Series Evaporators



First Cost

Operating Cost

Questions or Comments?