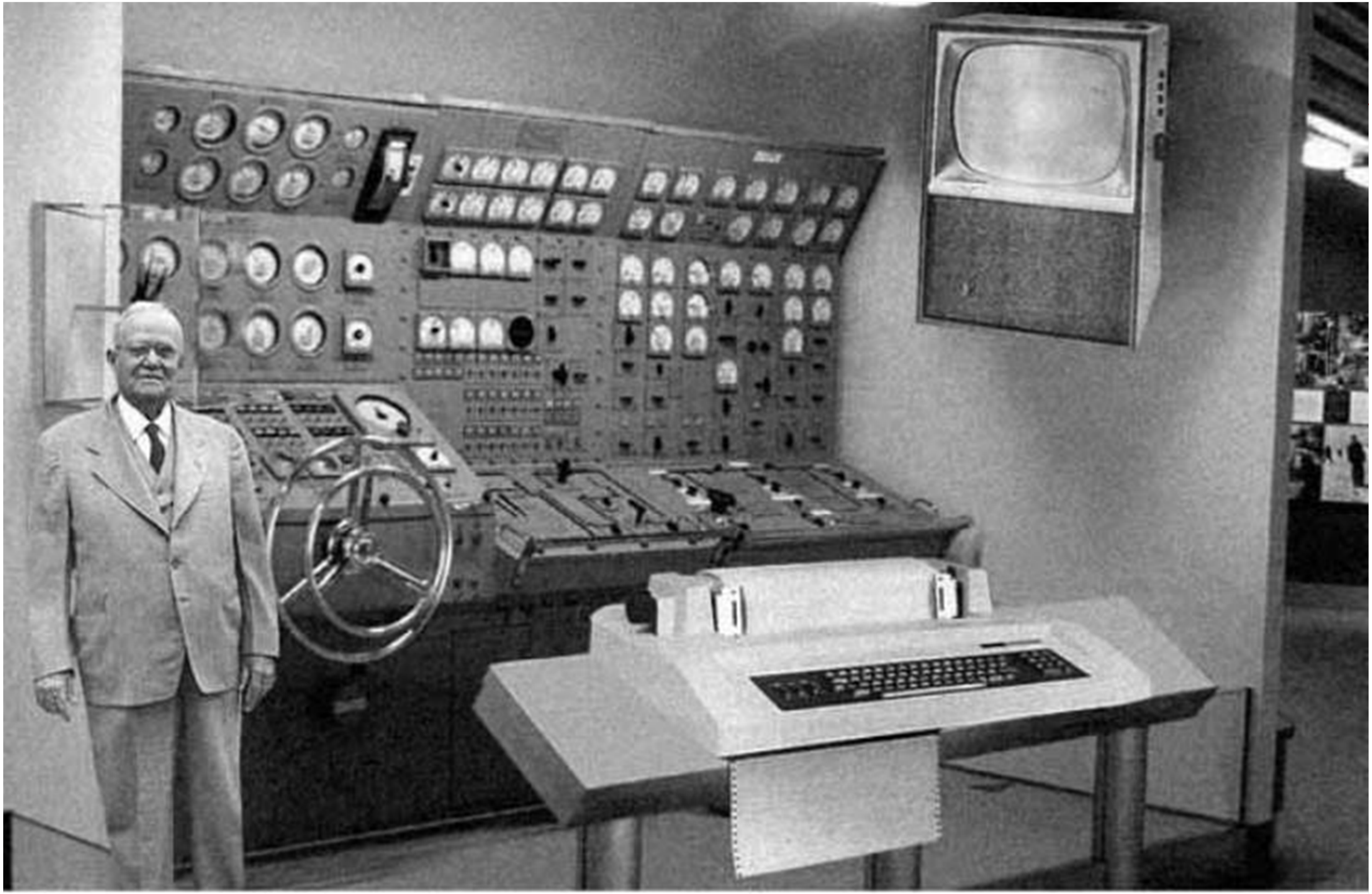
ASHRAE

Advancing HVAC&R to serve humanity and promote a sustainable world

Ultra Efficient Chiller Plants

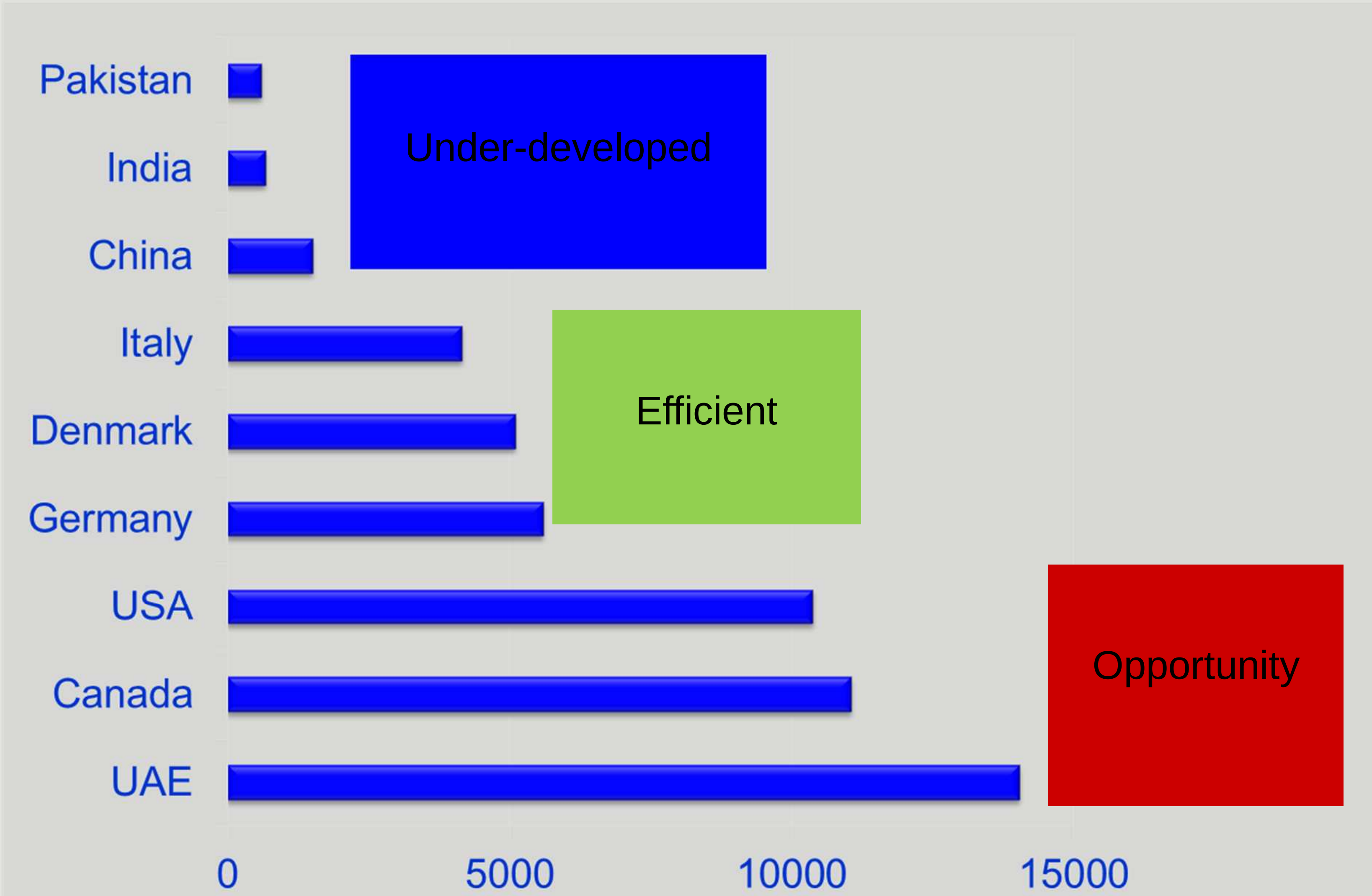
AGENDA

- Why Variable Speed?
- Why Variable Primary Flow?
- How to achieve energy savings with sensor placement?
- How to Design an Ultra-Efficient Chiller Plant
- All Variable Speed Plant Control
- Wrap-up & questions

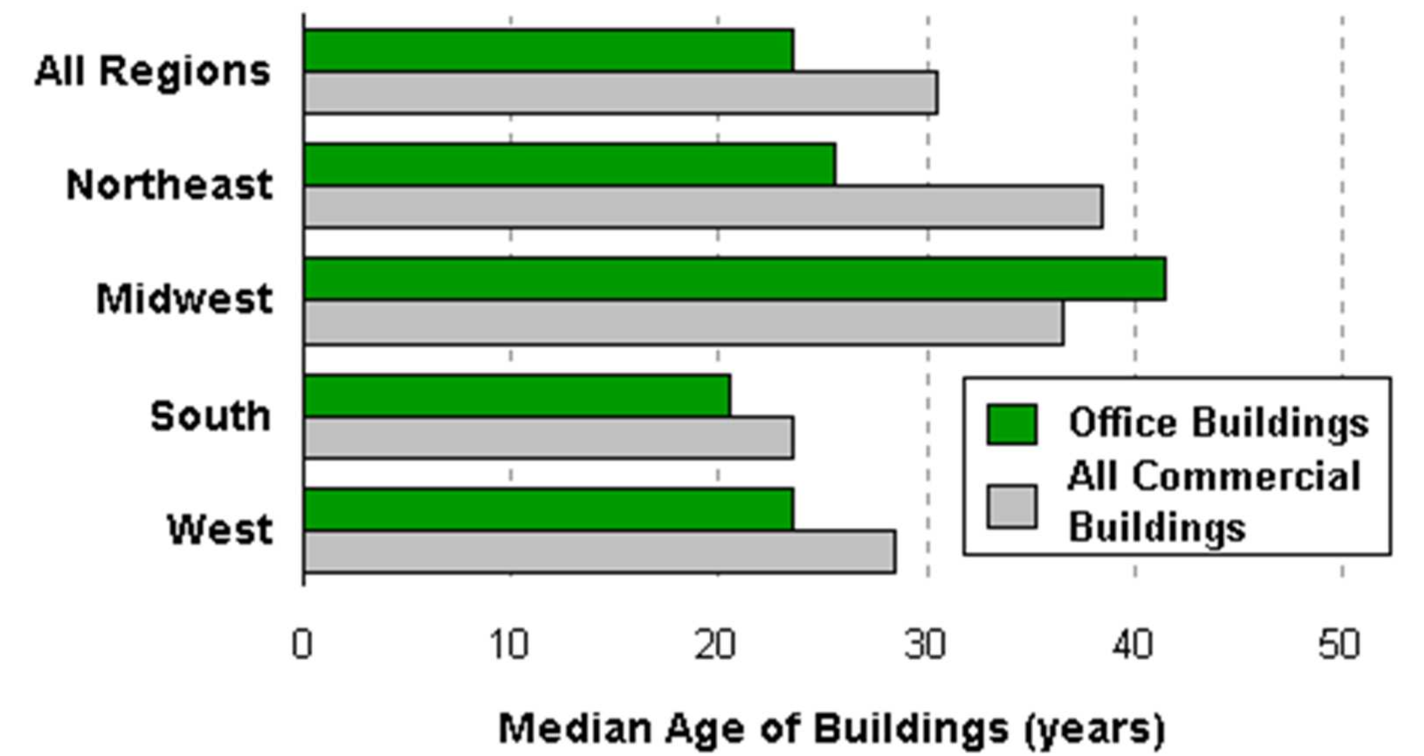


Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems. With teletype interface and the Fortran language, the computer will be easy to use.

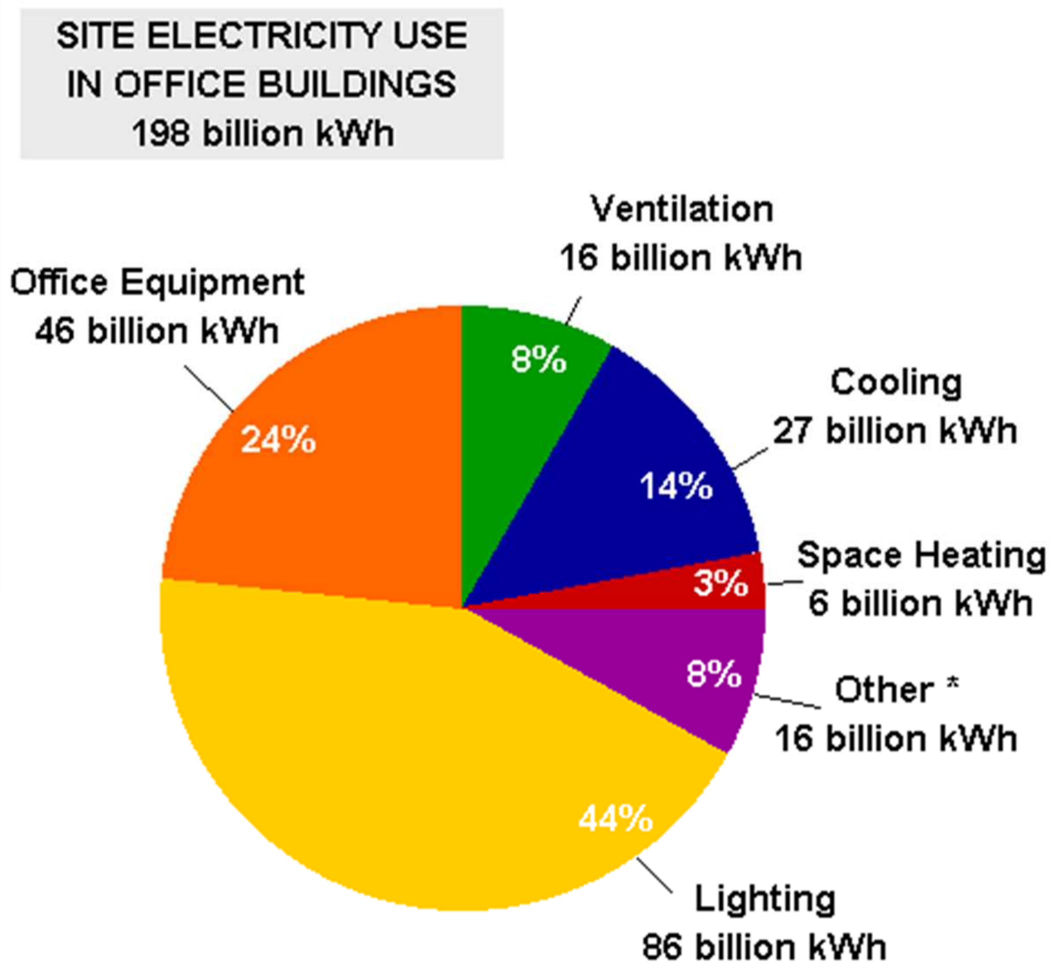
Watts Per Capita



North American Commercial Buildings are Aging



Source: Energy Information Administration, 1995 Commercial Buildings Energy Consumption Survey.



* Other includes miscellaneous uses (13 billion kWh), water heating (2 billion kWh), refrigeration (1 billion kWh), and cooking (<1 billion kWh).

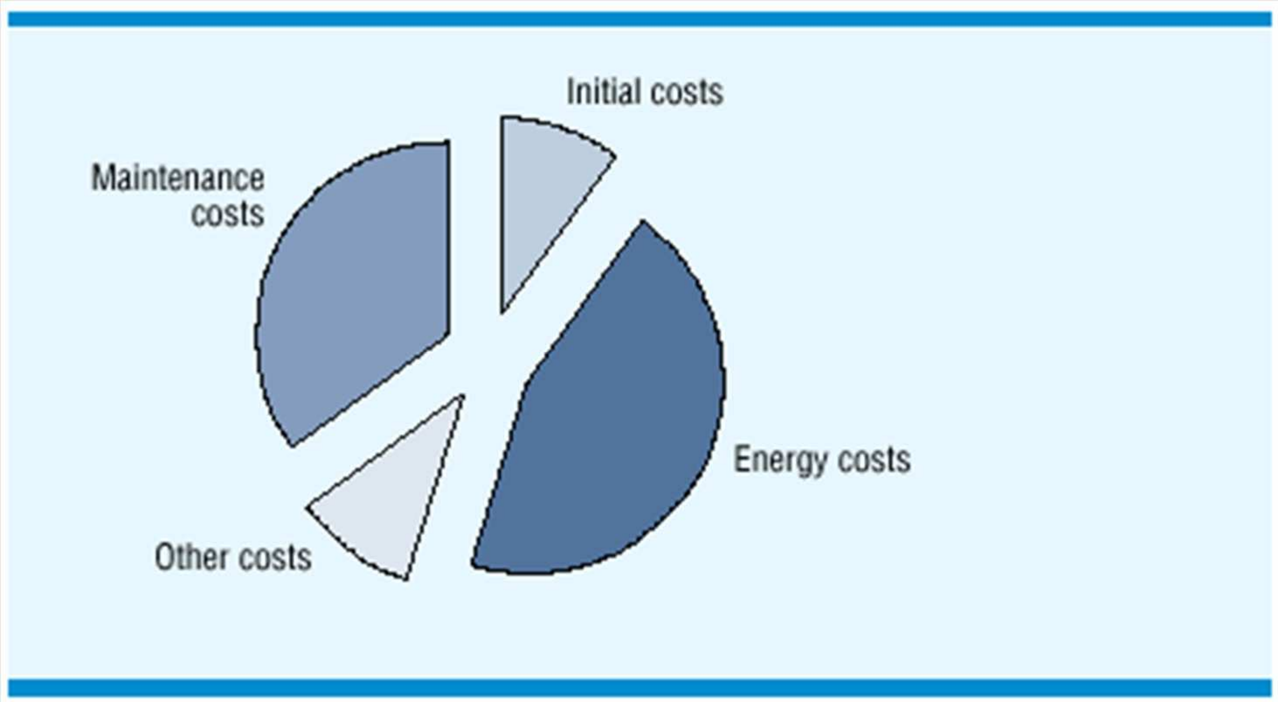
Note: Due to rounding, individual figures may not sum to totals.

Source: Energy Information Administration, 1995 Commercial Buildings Energy Consumption Survey.

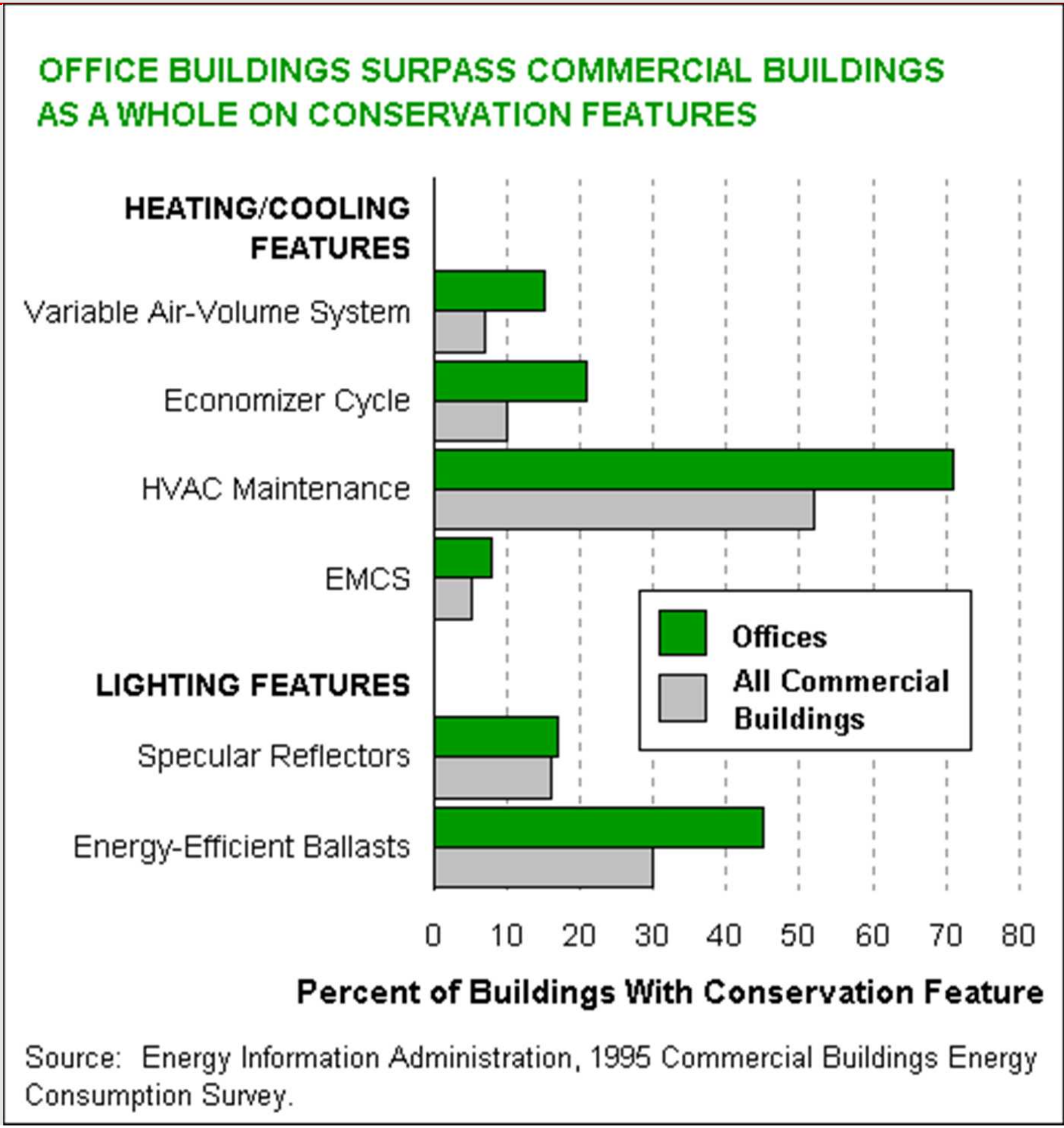
Life Cycle Cost

The life cycle cost (LCC) of any piece of equipment is the total "lifetime" cost to:

- **Purchase**
- **Install**
- **Operate**
- **Maintain**
- **Dispose of**



Hydraulic Institute Website


OFFICE BUILDINGS SURPASS COMMERCIAL BUILDINGS AS A WHOLE ON CONSERVATION FEATURES
HEATING/COOLING FEATURES
Variable Air-Volume System
Economizer Cycle
HVAC Maintenance
EMCS
LIGHTING FEATURES
Specular Reflectors
Energy-Efficient Ballasts
Offices
All Commercial Buildings
0
10
20
30
40
50
60
70
80
Percent of Buildings With Conservation Feature
Source: Energy Information Administration, 1995 Commercial Buildings Energy Consumption Survey.

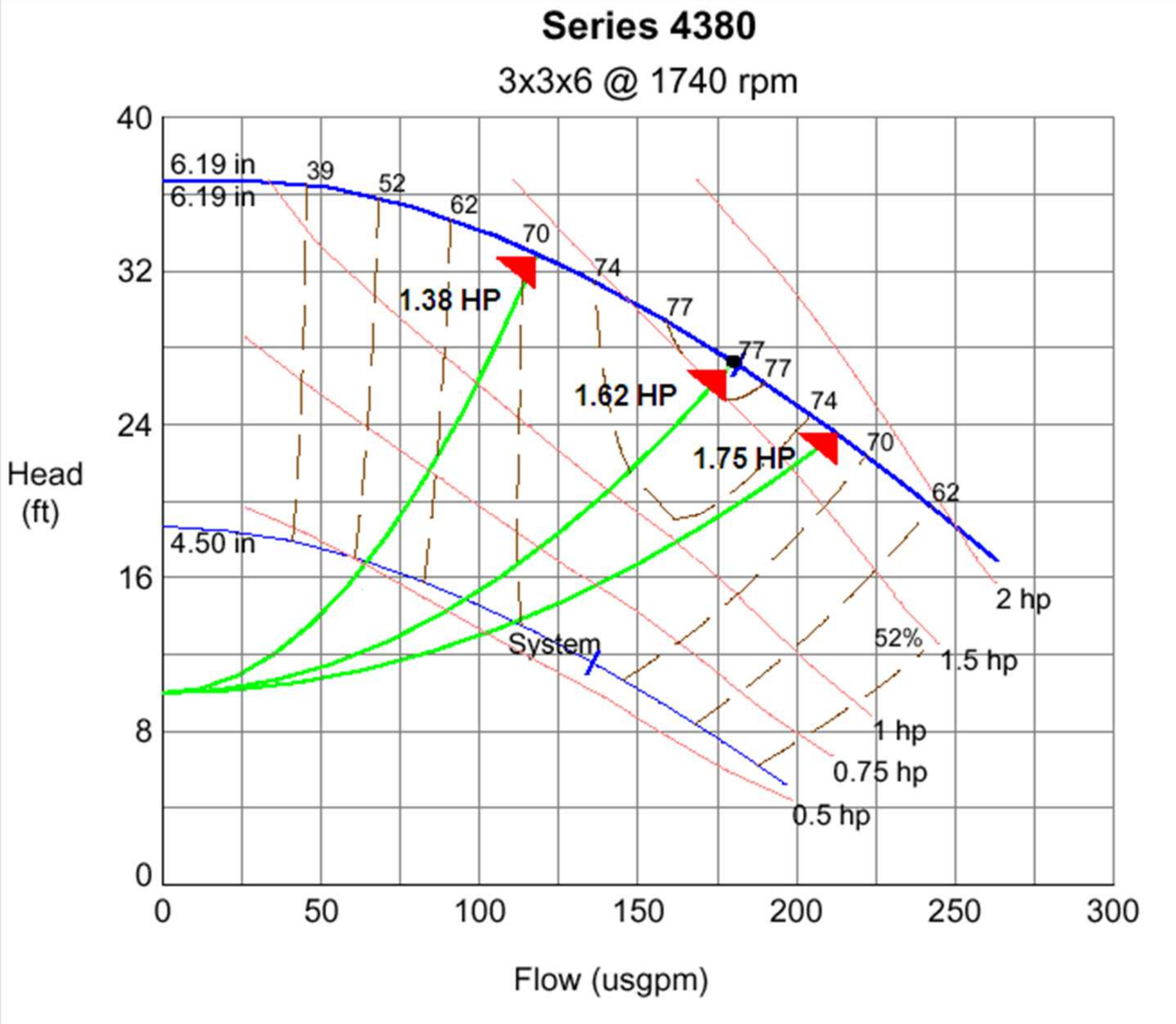
Why Variable Speed?

=

Constant Speed Energy Savings

Saving Energy With Constant Speed Pumps

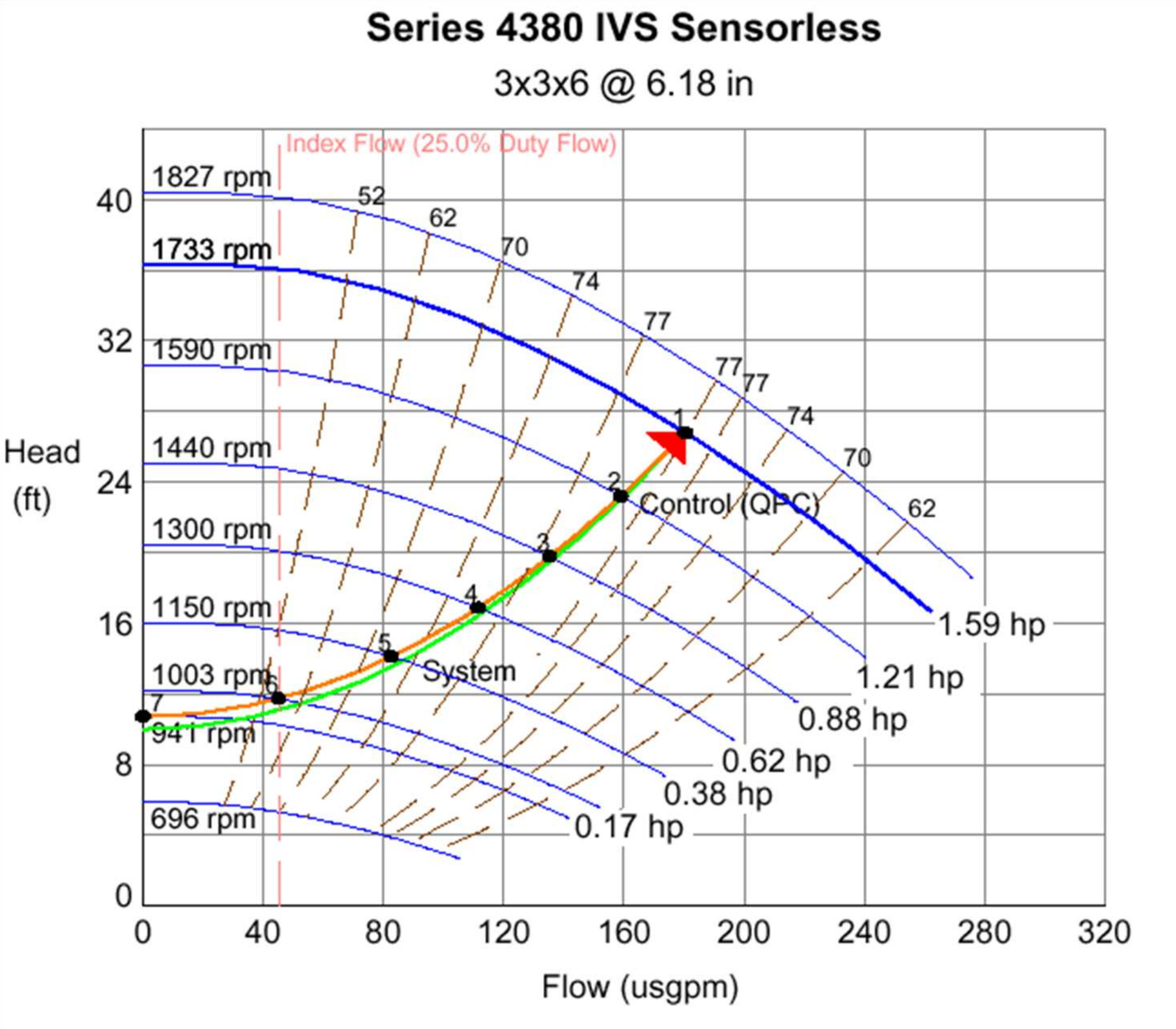
- Throttling Valves To “Ride” Pump Curve
- Riding the curve is ok to save a bit of pocket change
- Increased pressures can stress system components
- Automobile Analogy: Full throttle, maintain speed with brake



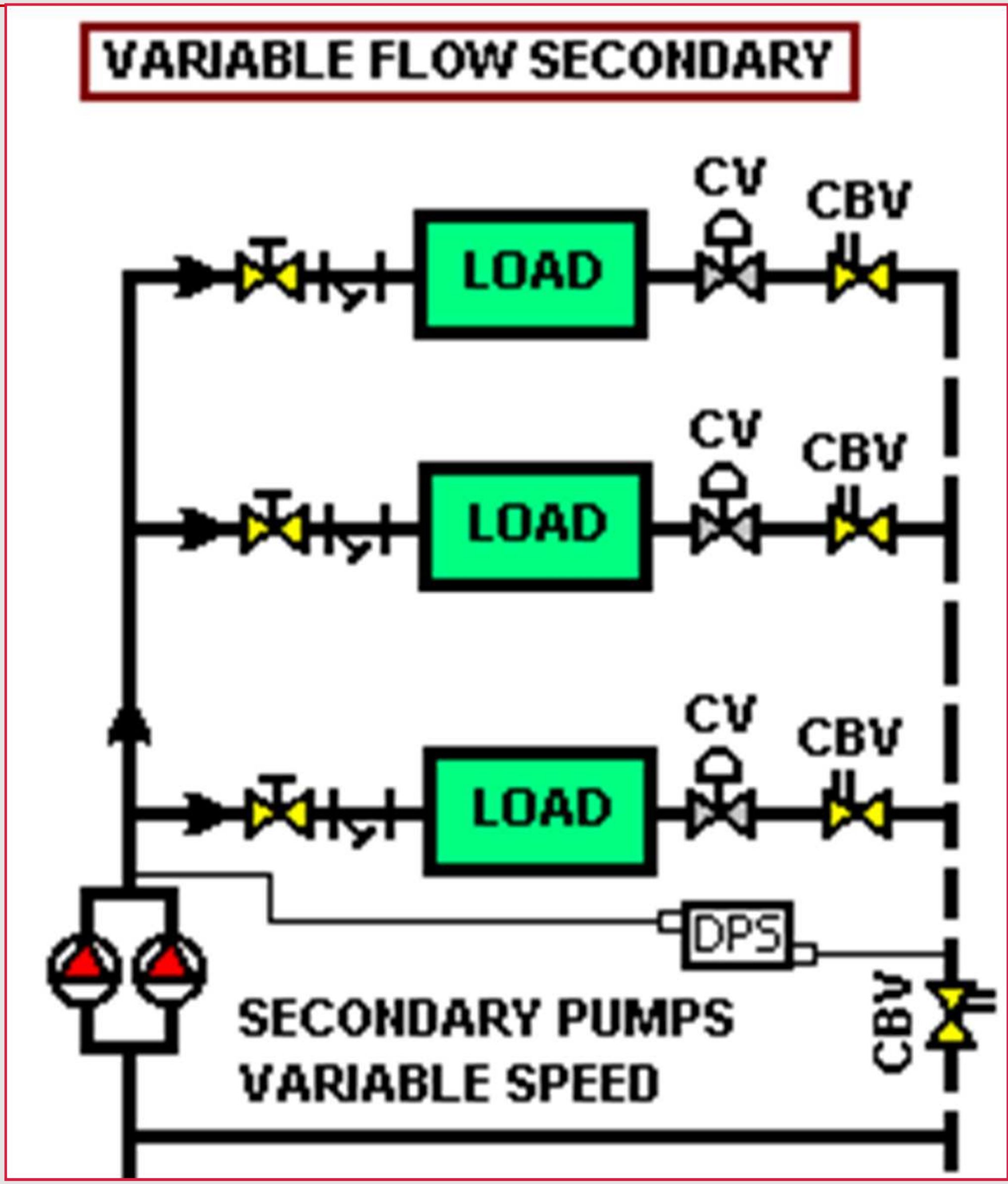
Variable Speed Energy Saving

Riding the system curve, however, is where the real money is!

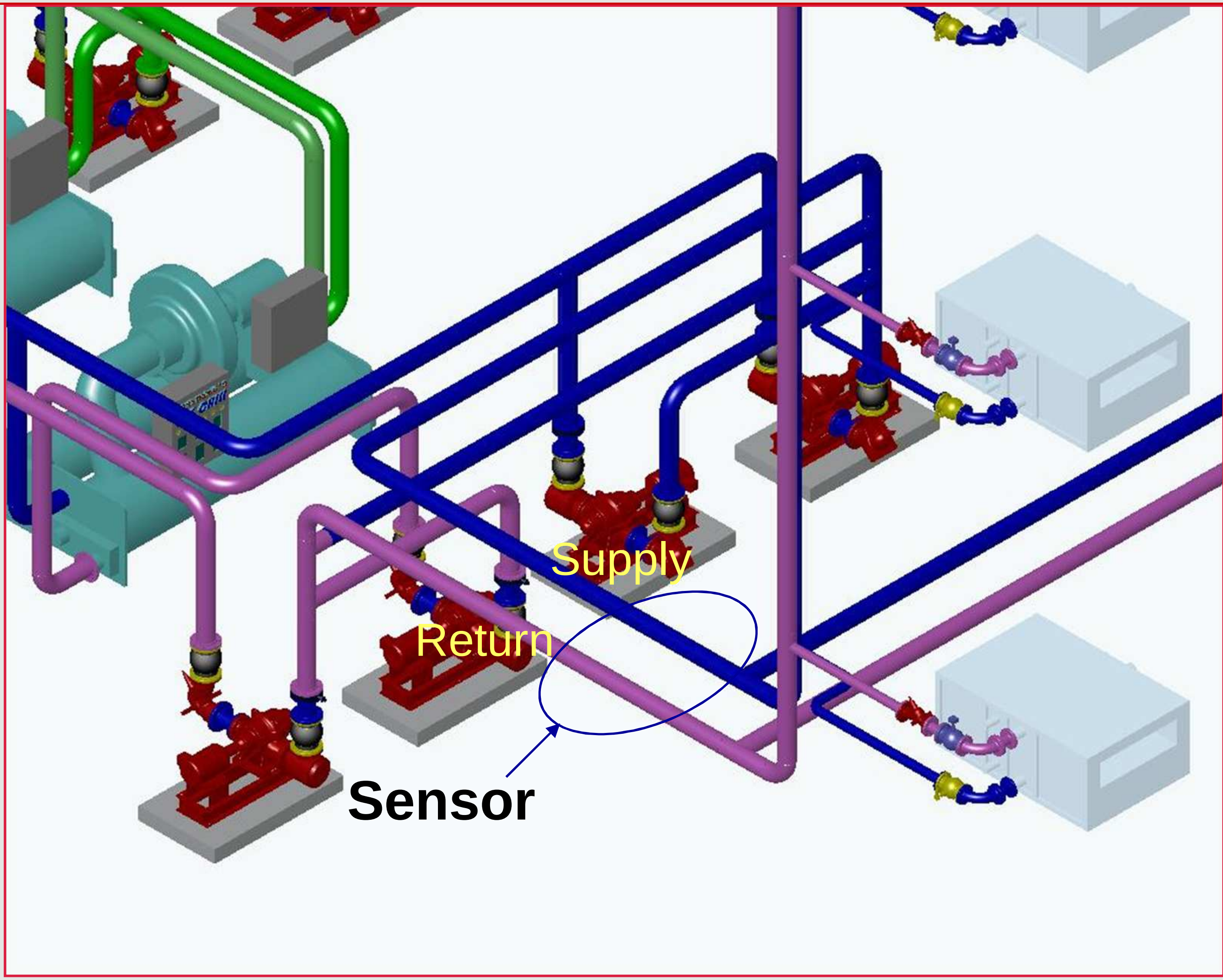
- Achieved with VFD Controller
- VFD varies the pump speed
- Reduced pressure for reduced flow
- Minimize excess wear on system components



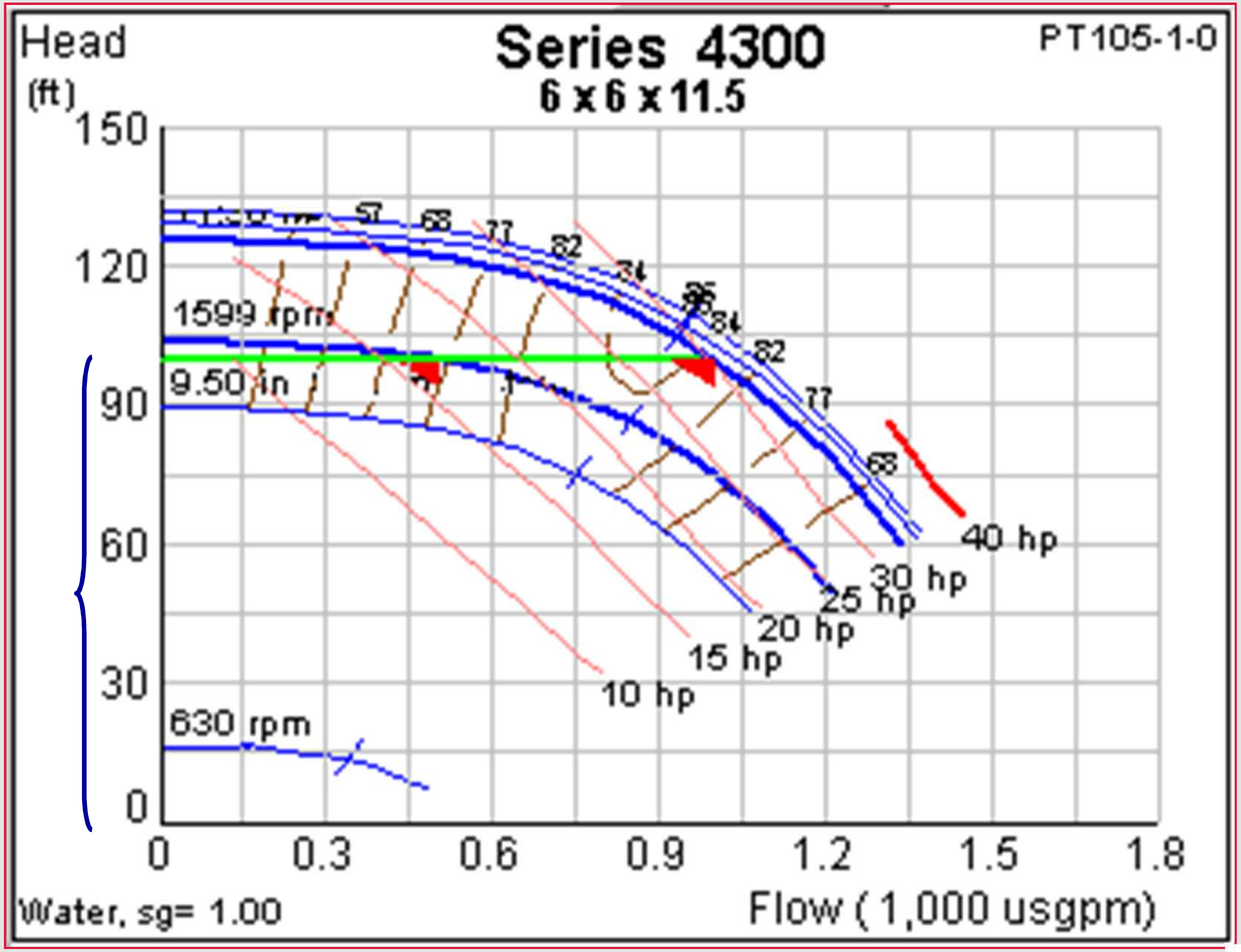
Typical *Level 1 Strategy* for Secondary Pumping Loop



Typical *Level 1 Strategy* for Secondary Pumping Loop



Flow @ 50% DP Sensor across pump (100 ft)



DP:
Sensor
Setting

Operating Point: 500 GPM @ 100 FT

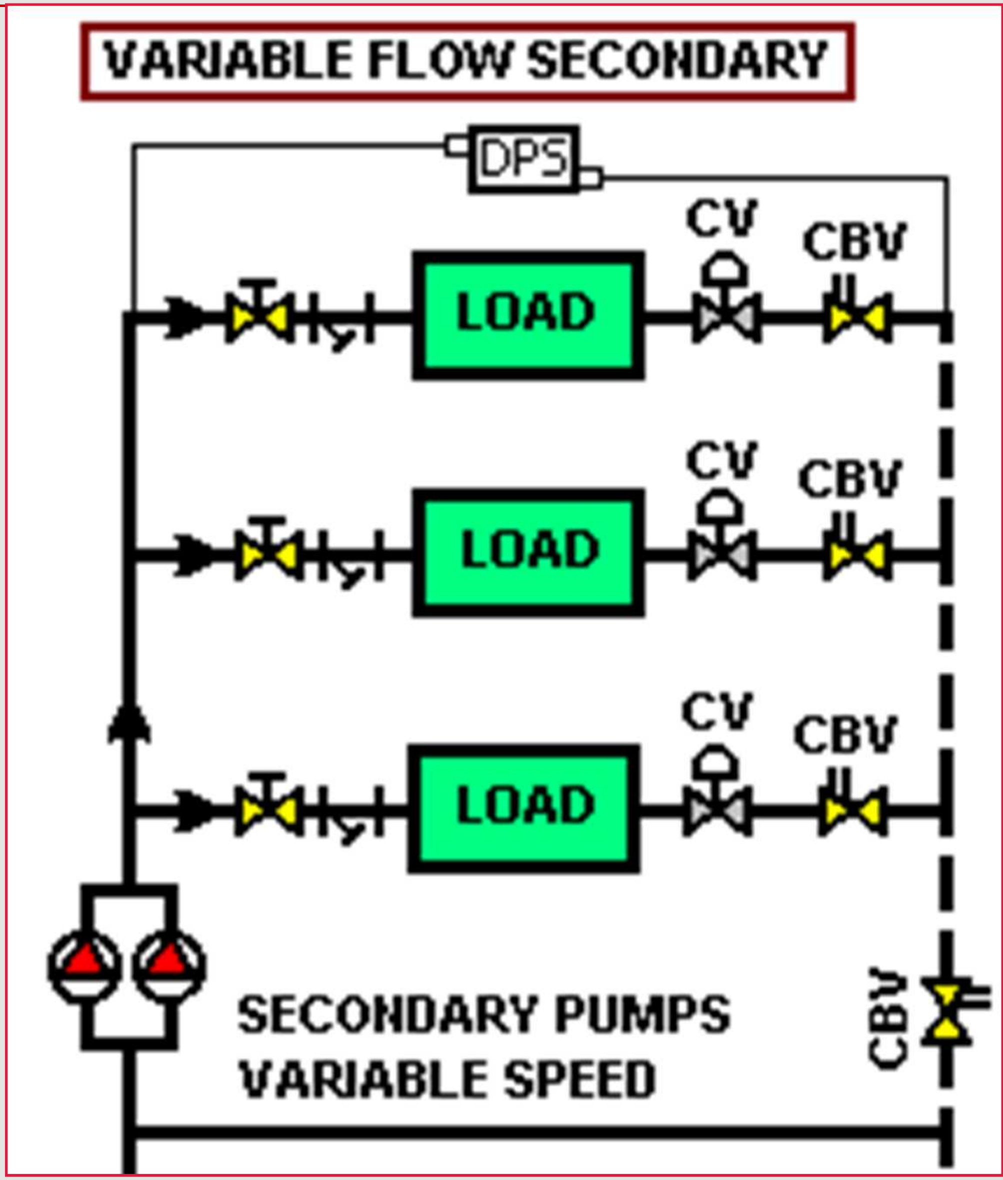
Power Savings: Flow @ 50% DP Sensor across pump

Usgpm	Ft. Hd	Pump RPM	Power HP	Efficiency
1000	100	1760	31.3	80.7
500	100	1599	17.5	72.0
	Power Savings:		44%	

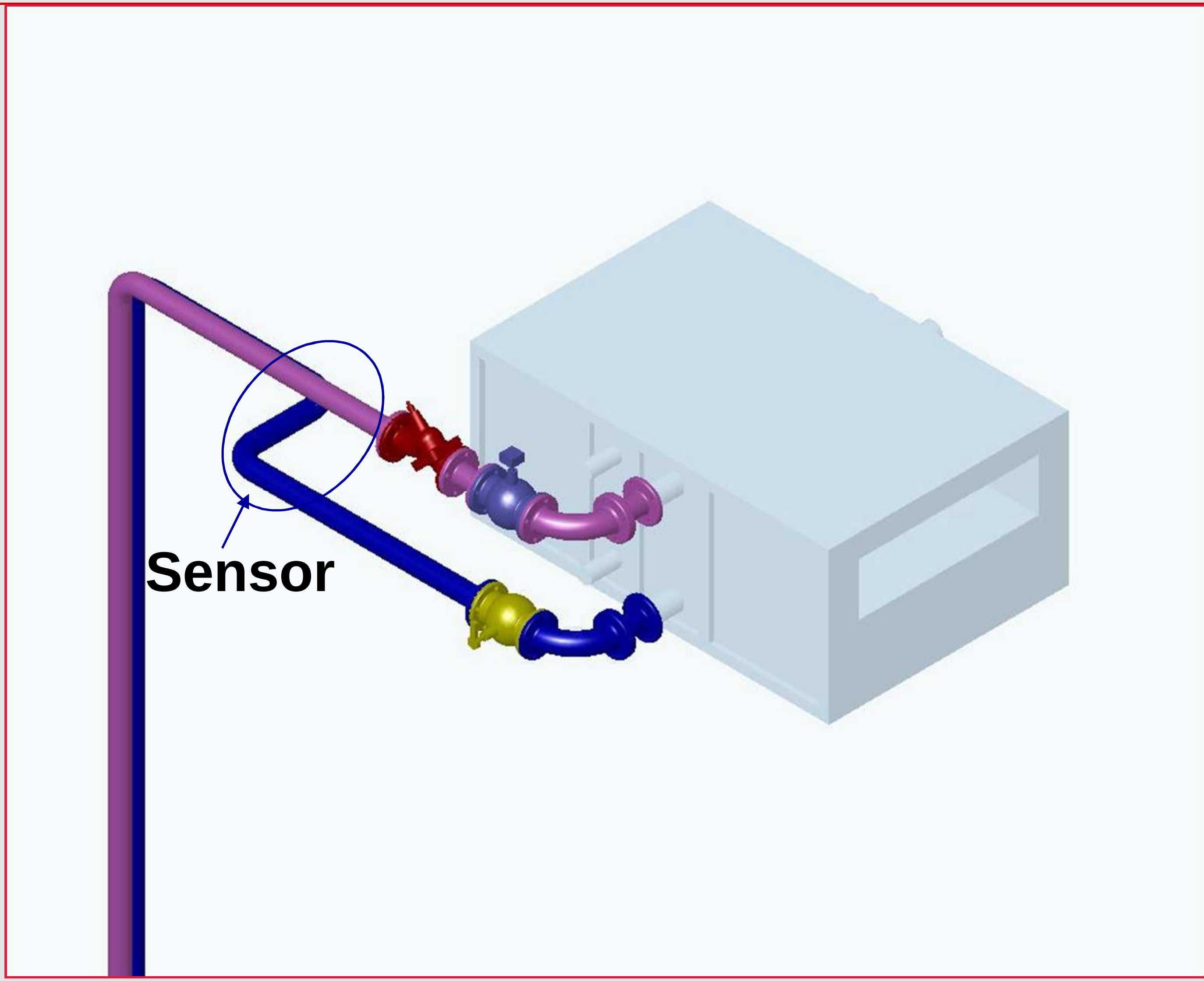
Additional Savings over riding pump curve: 22%

Not sufficient for ASHRAE 90.1

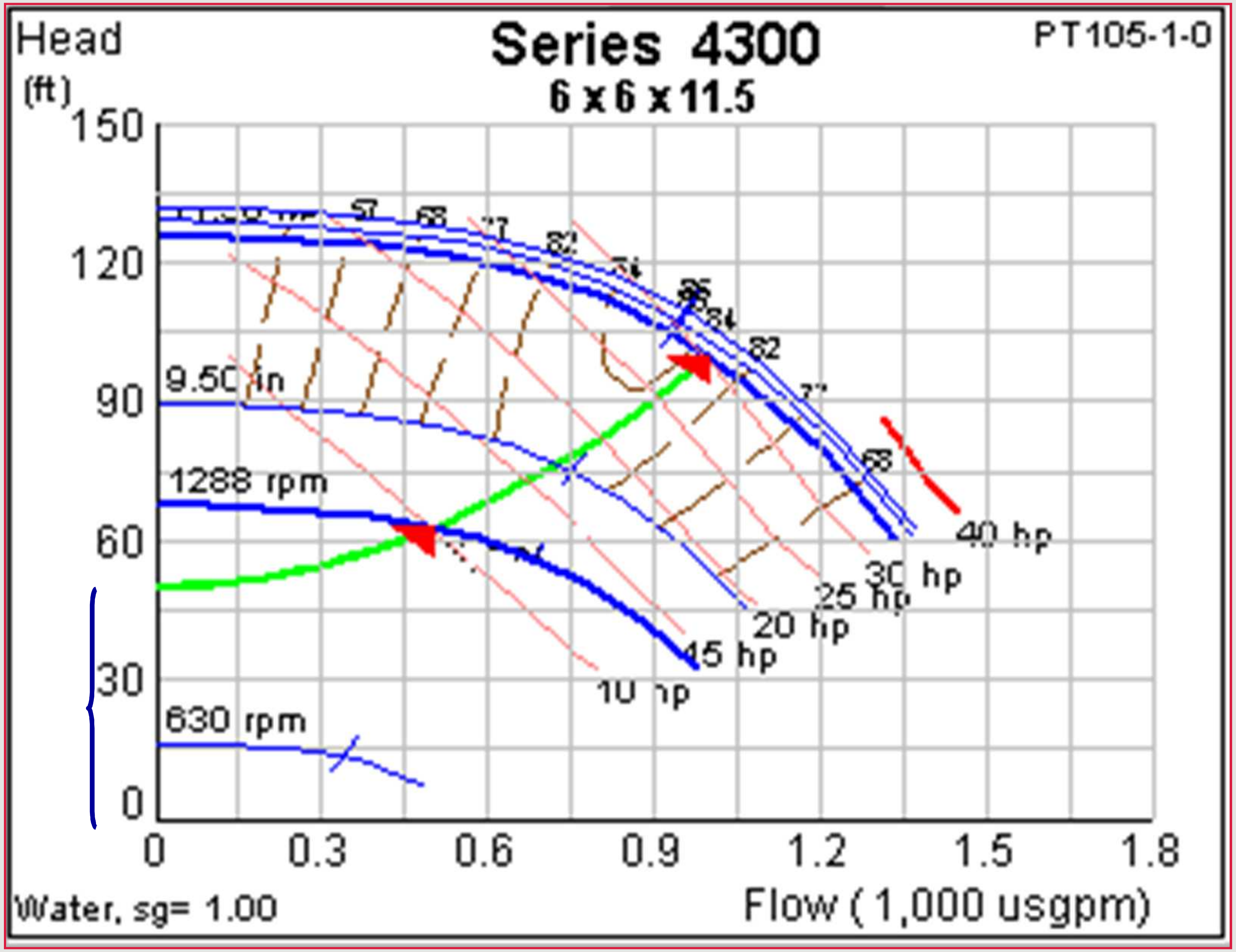
Typical *Level 2 Strategy* for Secondary Pumping Loop



Typical *Level 2 Strategy* for Secondary Pumping Loop



Flow @ 50% DP Sensor across Coil & CV



DP:
Sensor
Setting

OPERATING POINT: 500 GPM @ 63 FT

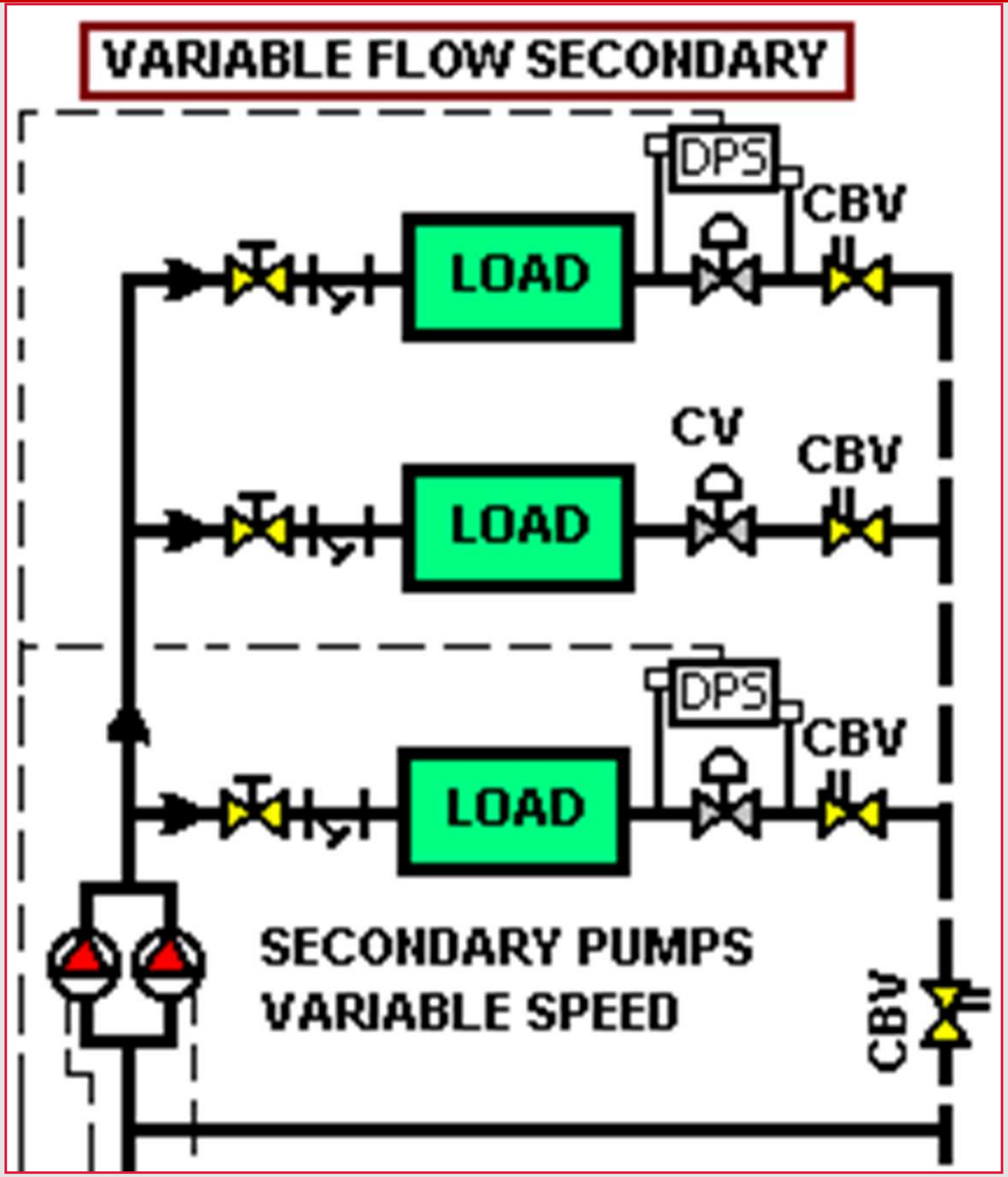
Power Savings: Flow @ 50% DP Sensor across coil & CV

Usgpm	Ft. Hd	Pump RPM	Power HP	Efficiency
1000	100	1760	31.3	80.7
500	63	1288	10.2	78.2
	Power Savings:		67%	

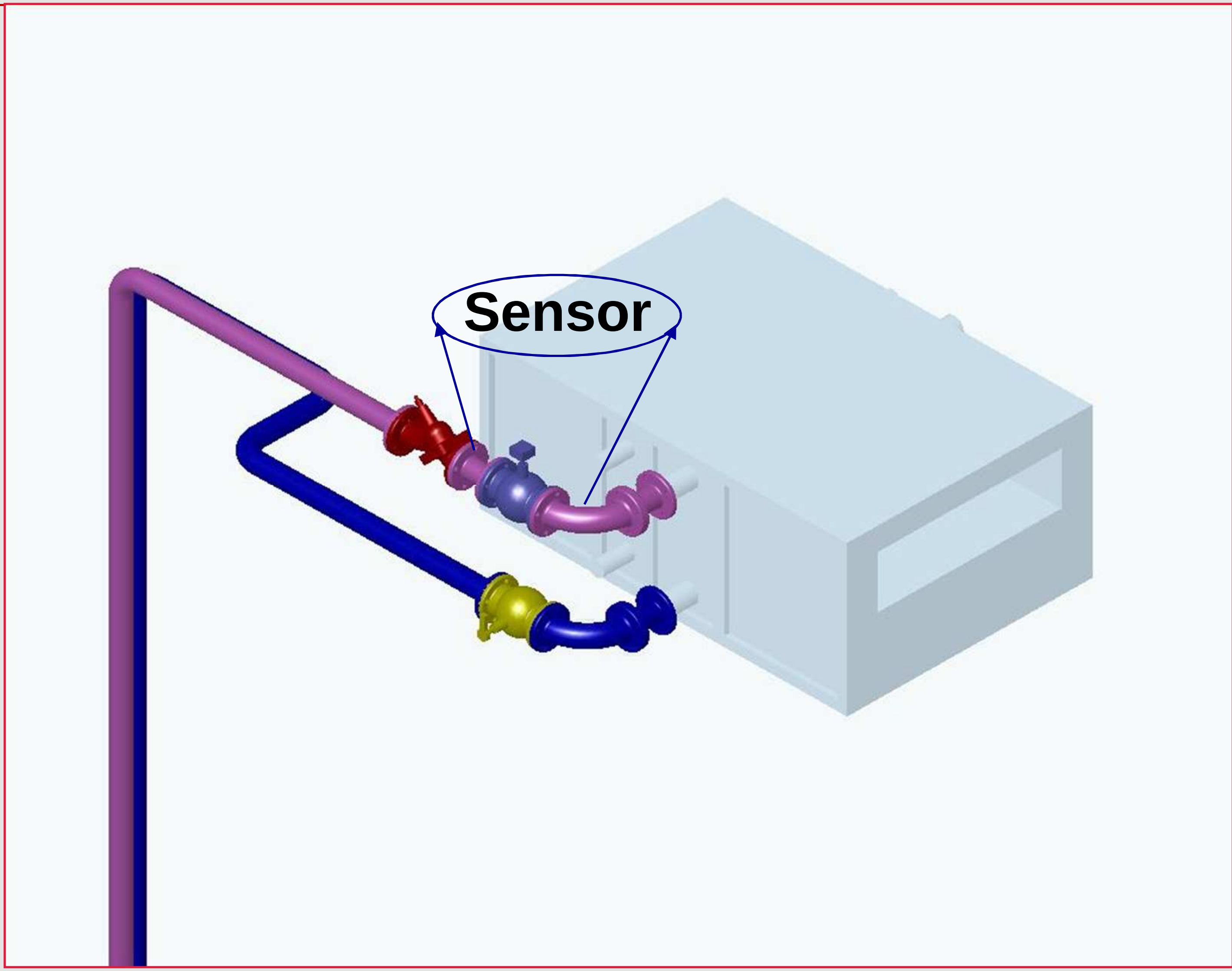
Additional Savings over maintaining plant DP: 42%

On track for ASHRAE 90.1 requirements

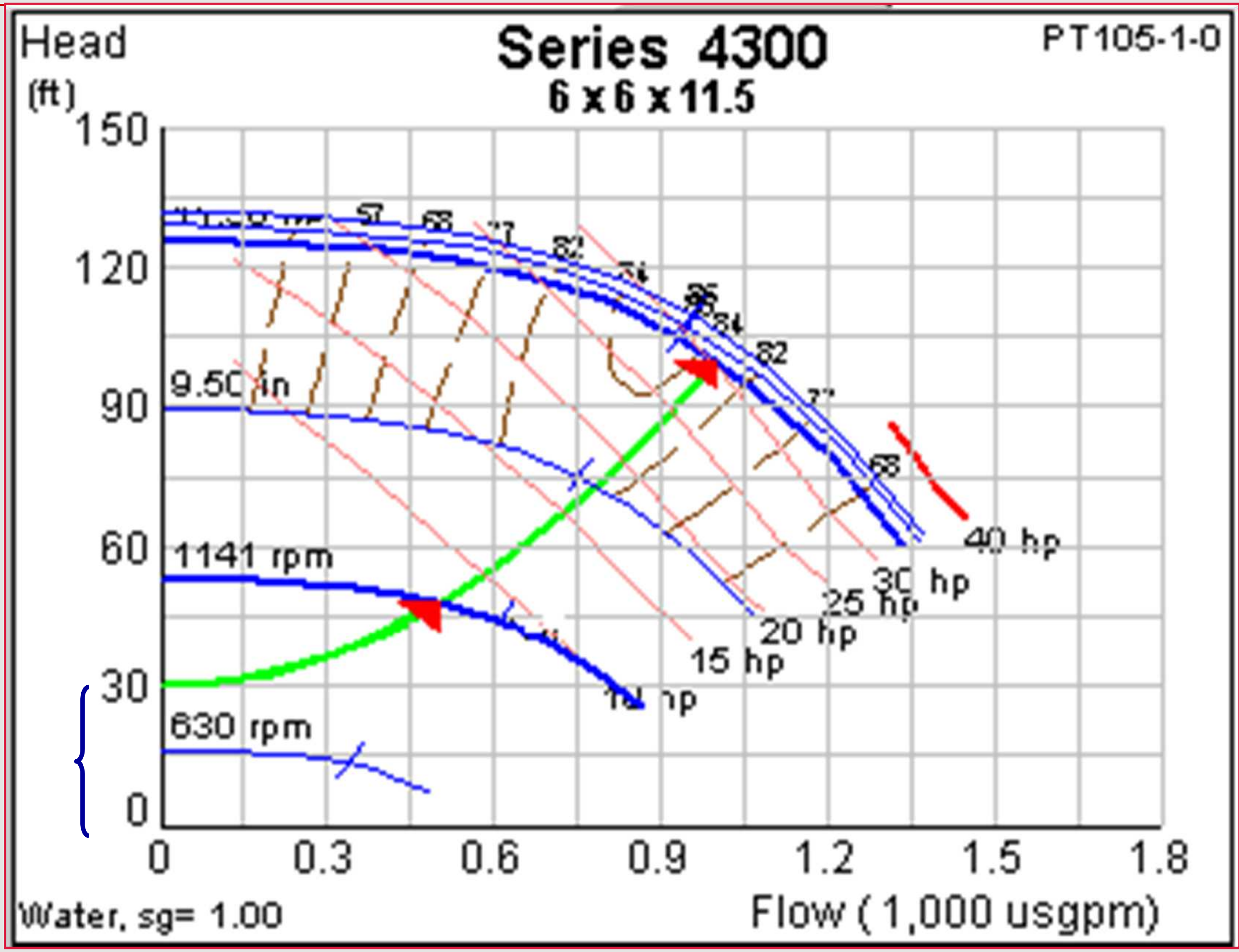
Typical *Level 3 Strategy* for Secondary Pumping Loop



Typical *Level 3 Strategy* for Secondary Pumping Loop



Flow @ 50% DP Sensor across CV



DP:
Sensor
Setting

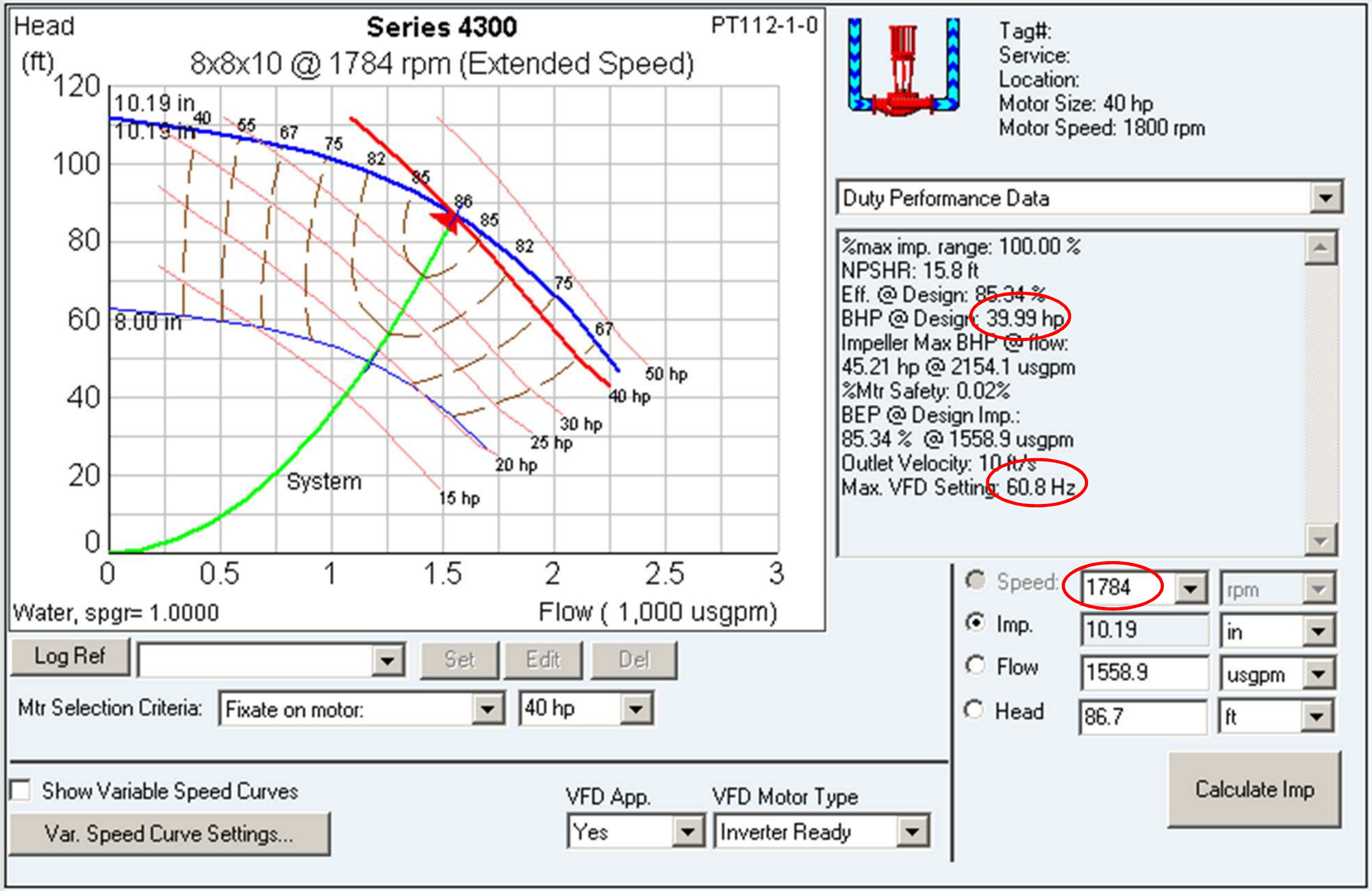
Operating Point: 500 GPM @ 48 FT

Power Savings: Flow @ 50% DP Sensor across CV (30 ft)

Usgpm	Ft. Hd	Pump RPM	Power HP	Efficiency
1000	100	1760	31.3	80.7
500	48	1141	7.5	80.4
	Power Savings:		76%	

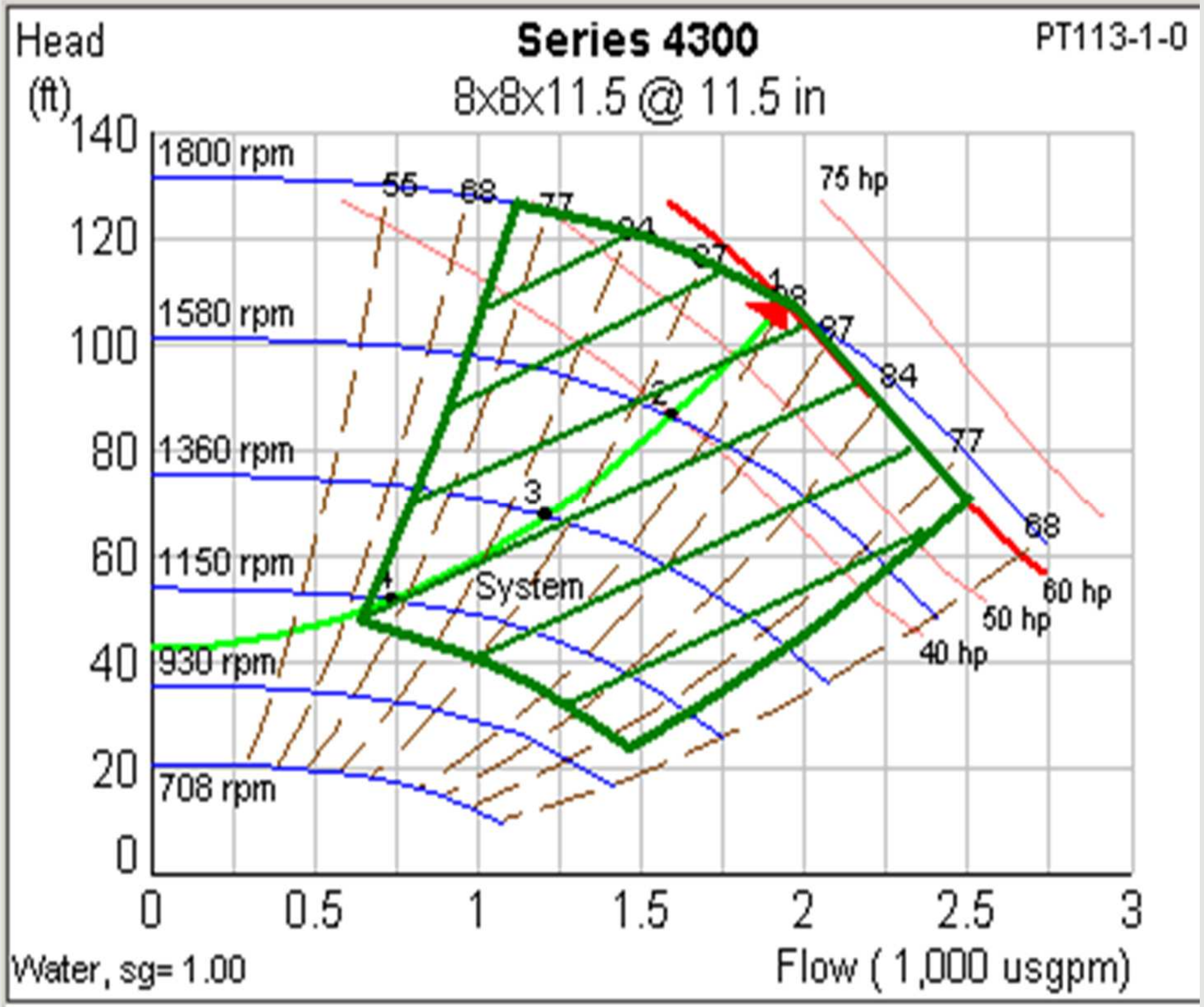
Additional Savings over maintaining Load Zone DP: 26%
ASHRAE 90.1 requirements well served

Maximum capability for motor size



Impeller & Speed selected to maximize largest installed motor

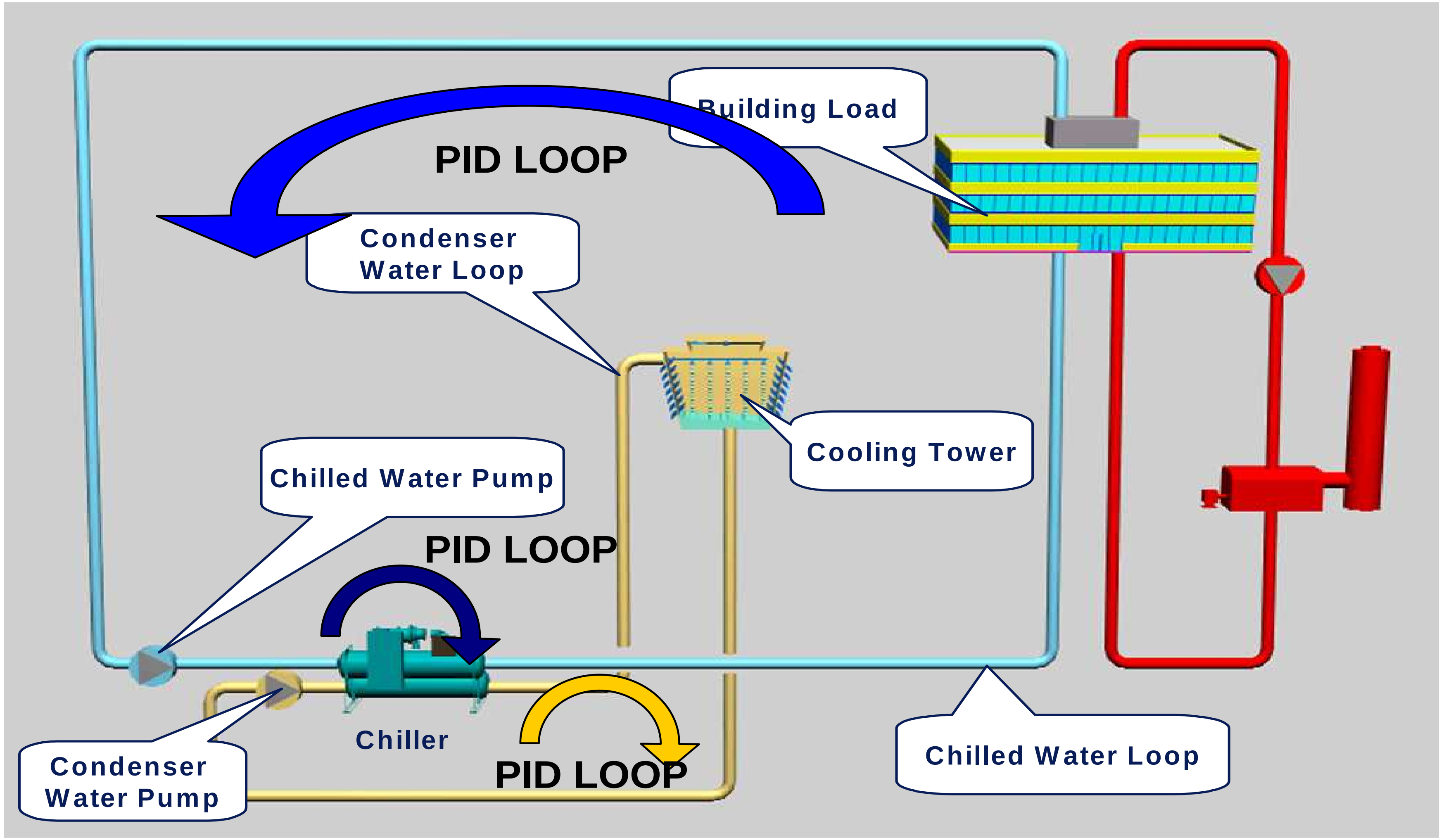
Maximum capability for motor size



Resulting Design Envelope (DE) Note that DE follows motor power line not impeller curve beyond BEP

Ultra-Efficient Chiller Plants

Ultra Efficient Chilled Water Plant Control For The All-Variable Speed Plant



Three PID Loops, behaving independently.
Capacity based sequencing.
Complex “reset” for strategies for light load.

What is "today's standard"?

0.7 – 1.1 kW/Ton

Annual Average

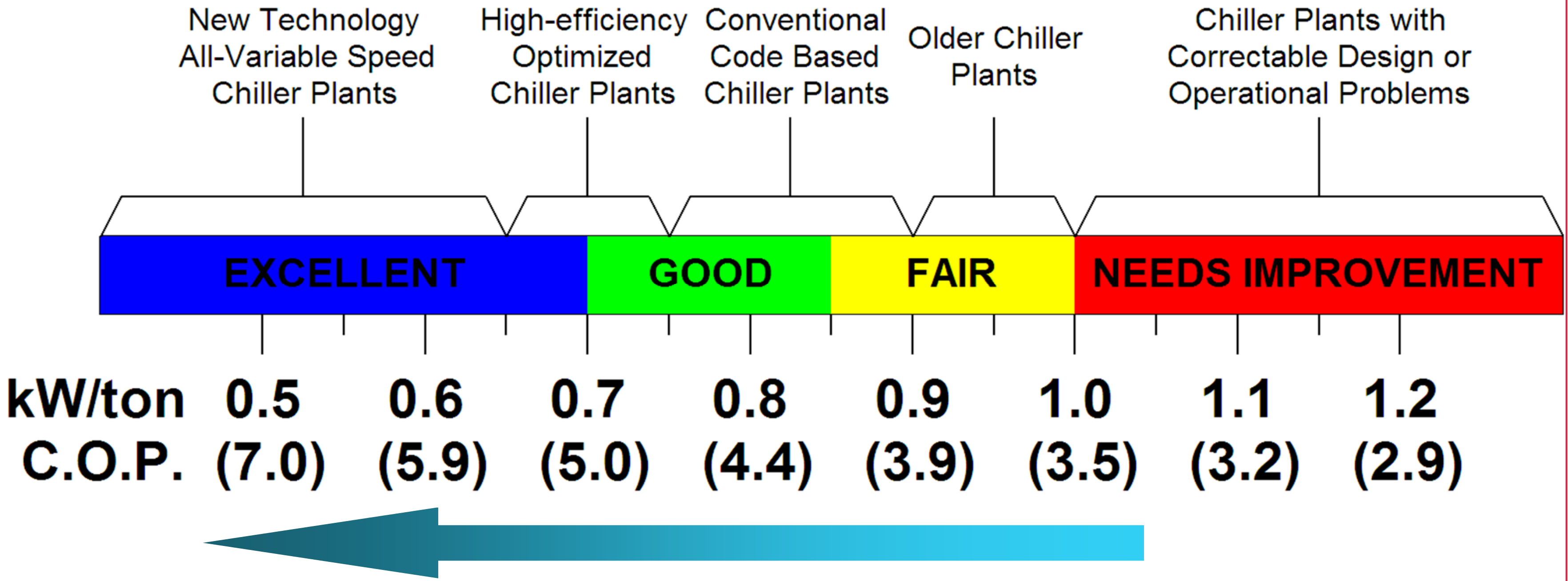
(Water Cooled Chilled Water Plant)

What is "Ultra-Efficient"?

<0.45 kW/ton

Annual Average

Chiller Plant Energy Use Spectrum



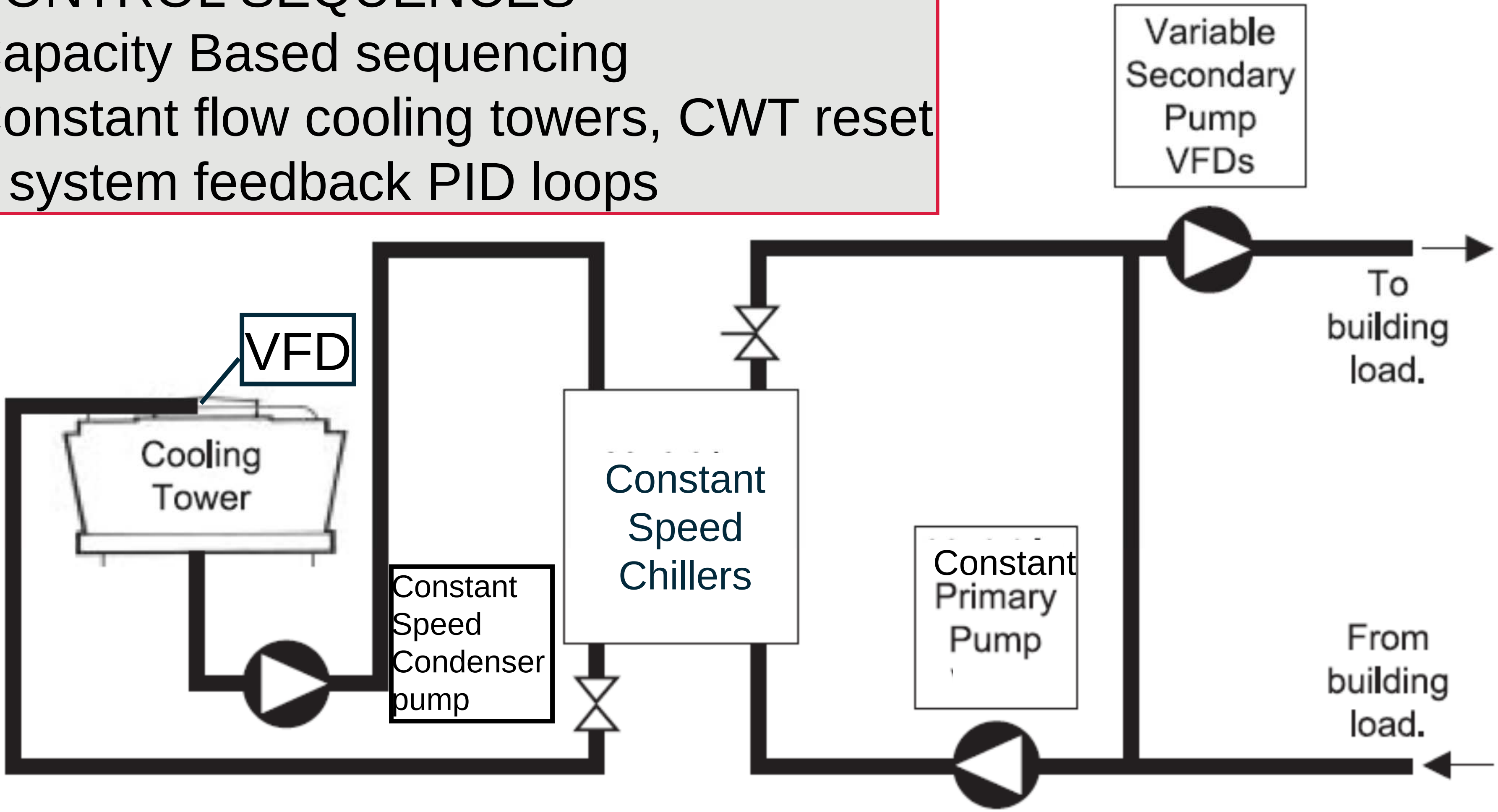
AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, condenser pumps and tower fans)

Based on electrically driven centrifugal chiller plants in comfort conditioning applications with 42F (5.6C) nominal chilled water supply temperature and open cooling towers sized for 85F (29.4C) maximum entering condenser water temperature. Local Climate adjustment for North American climates is +/- 0.05 kW/ton

What is "Typical"?

Constant Speed Primary, variable speed / flow secondary

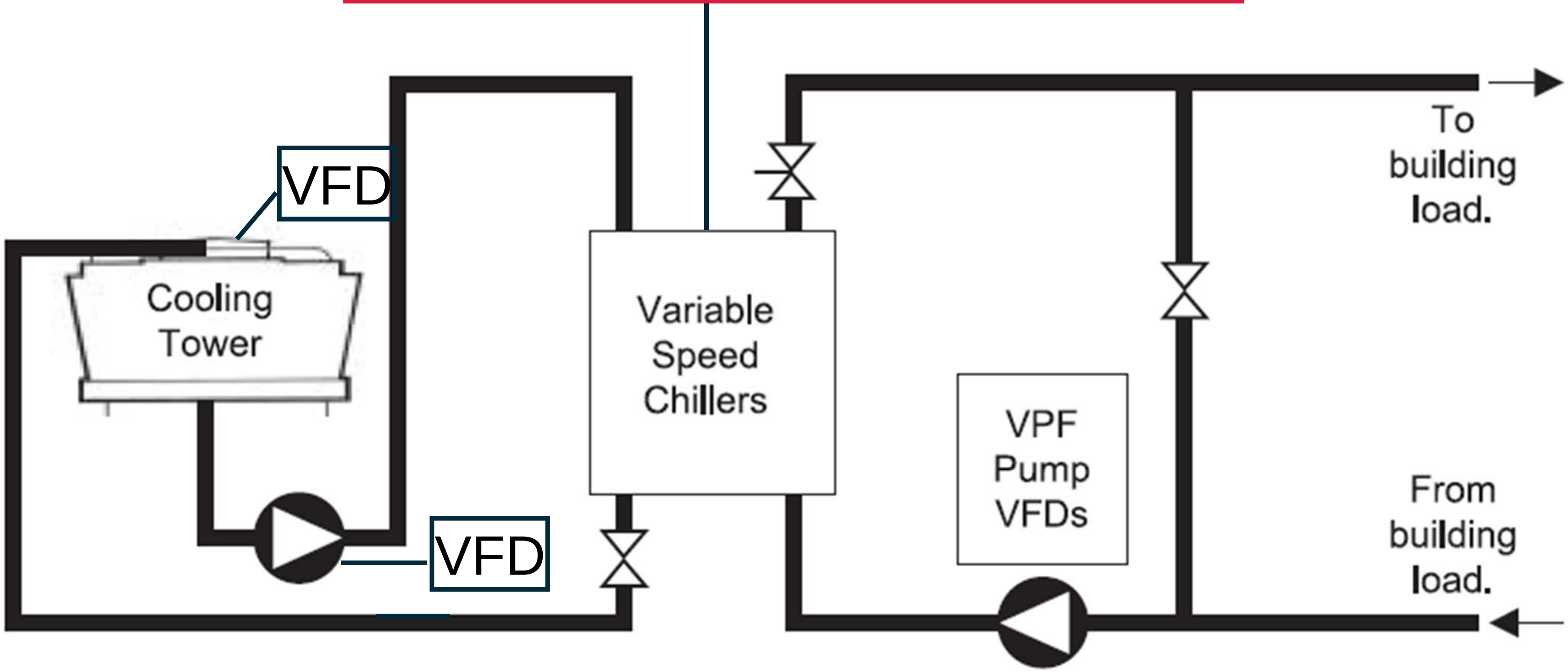
CONTROL SEQUENCES
Capacity Based sequencing
Constant flow cooling towers, CWT reset
3 system feedback PID loops



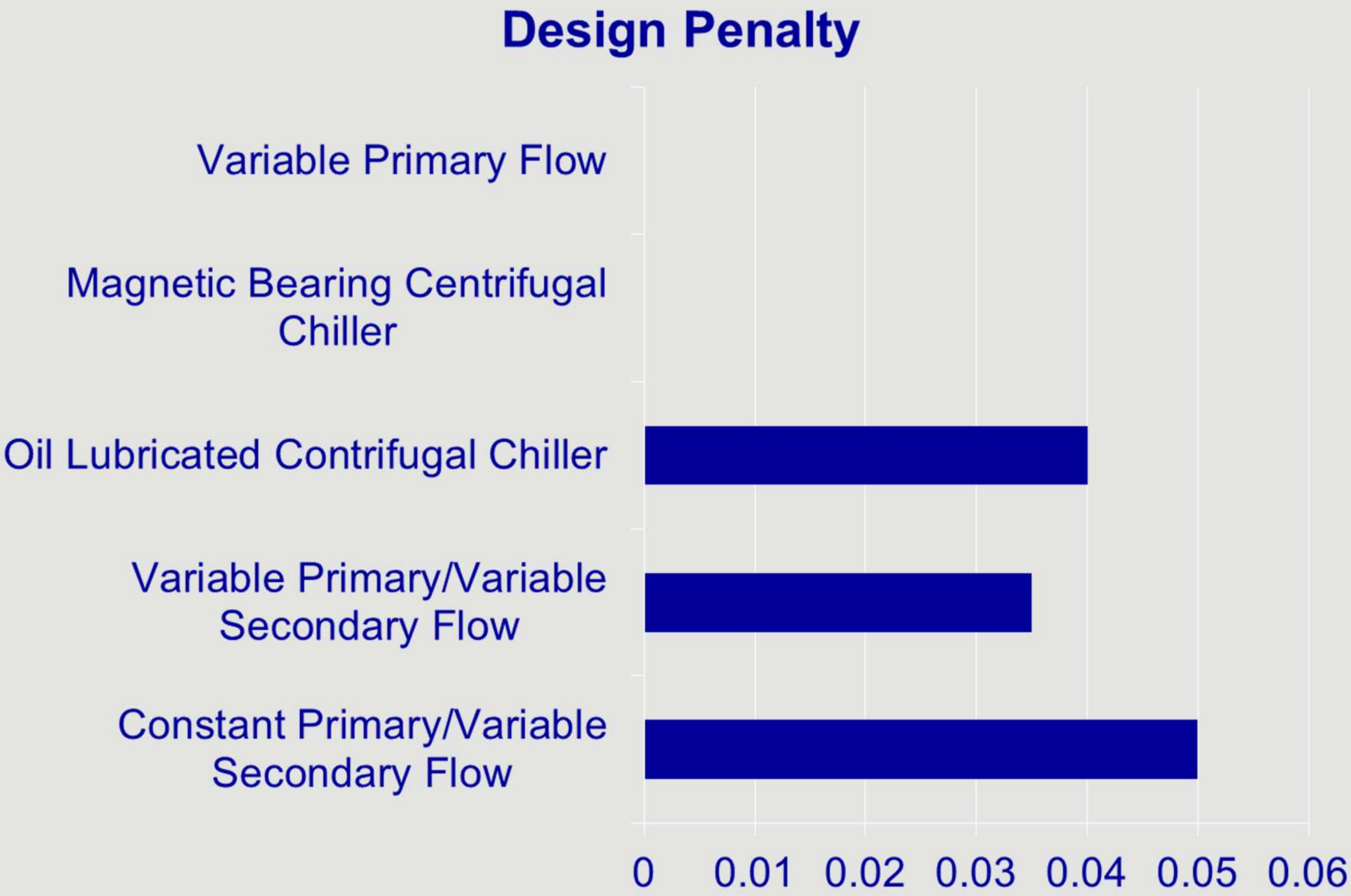
What is “ultra-efficient”?

All variable speed plant with variable speed tower pump, tower fan, primary pump, and secondary pump

CONTROL SEQUENCES
Natural Curve Sequencing
Equal Marginal Performance Principle
Demand Based Control



Begin With the Best Design



Achieving Integrated Plant Control

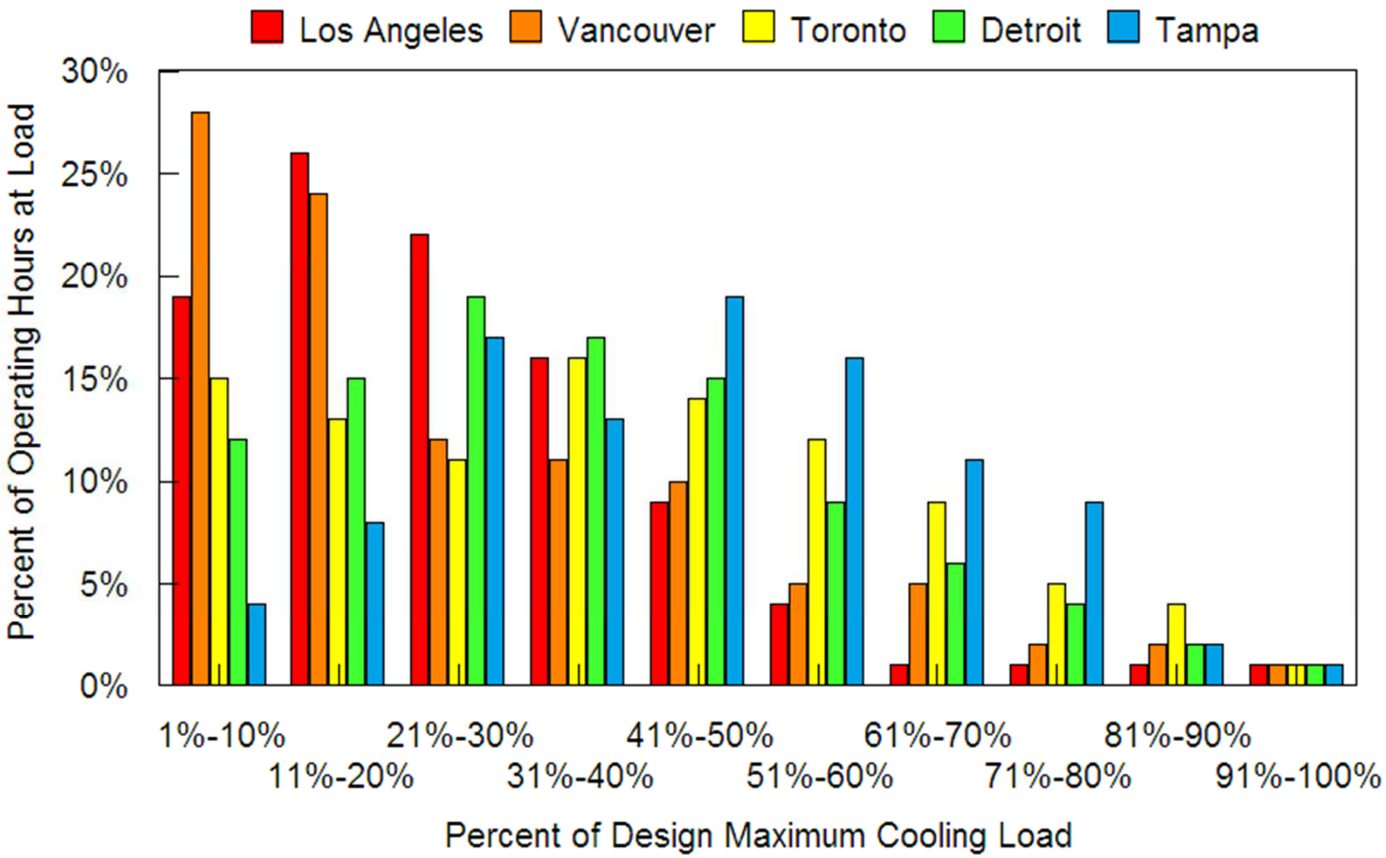
Based on “Hartman LOOP® Technology”

THIS PRODUCT EMPLOYS
Hartman LOOP™
TECHNOLOGIES

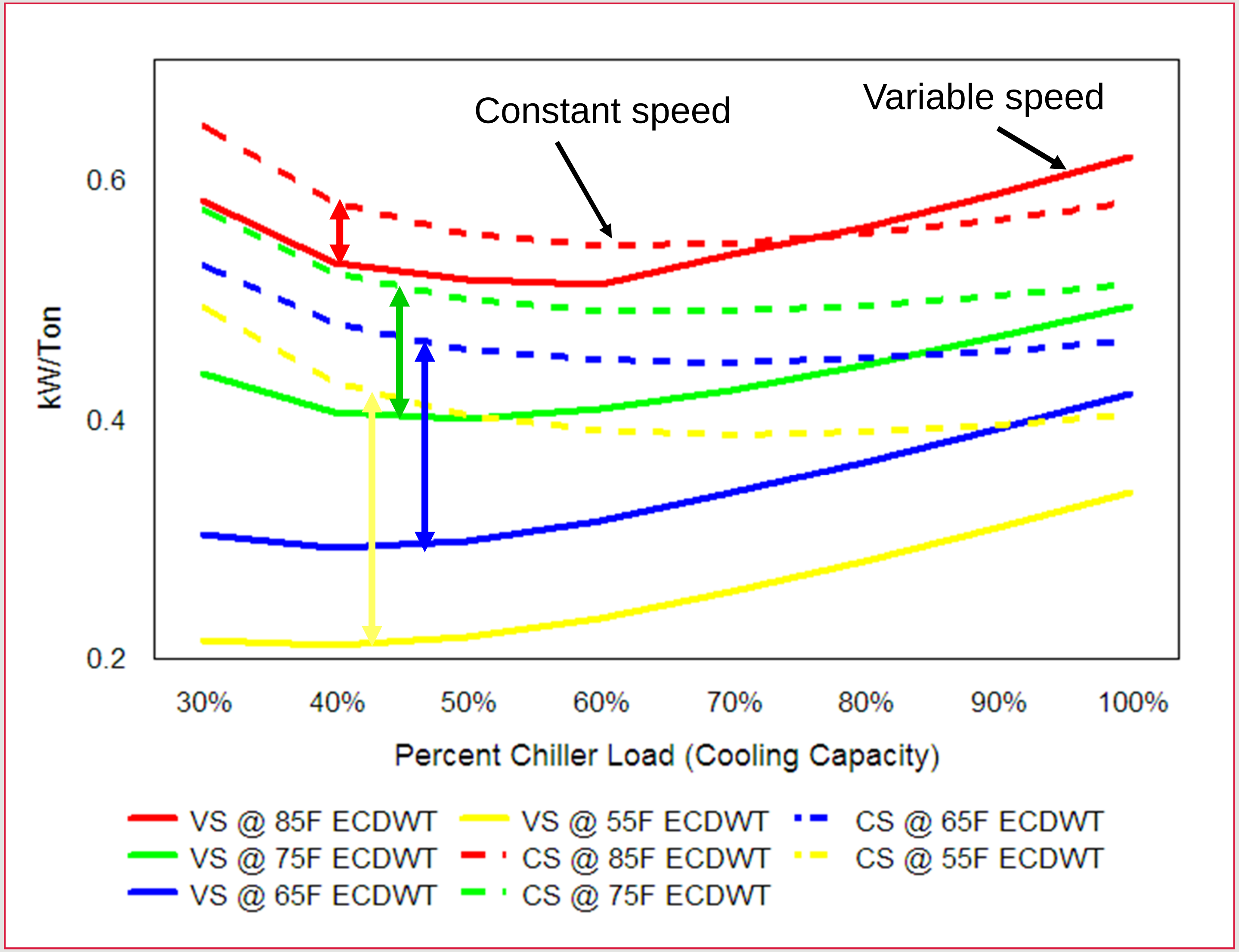
Patented under one or more of U.S. Patent
Nos. 5,946,926 6,185,946 6,257,007B1

- Natural Curve
- Equal Marginal Performance Principle
- Demand Based Control

Algorithm Based on Comfort Cooling as a Part Load Application



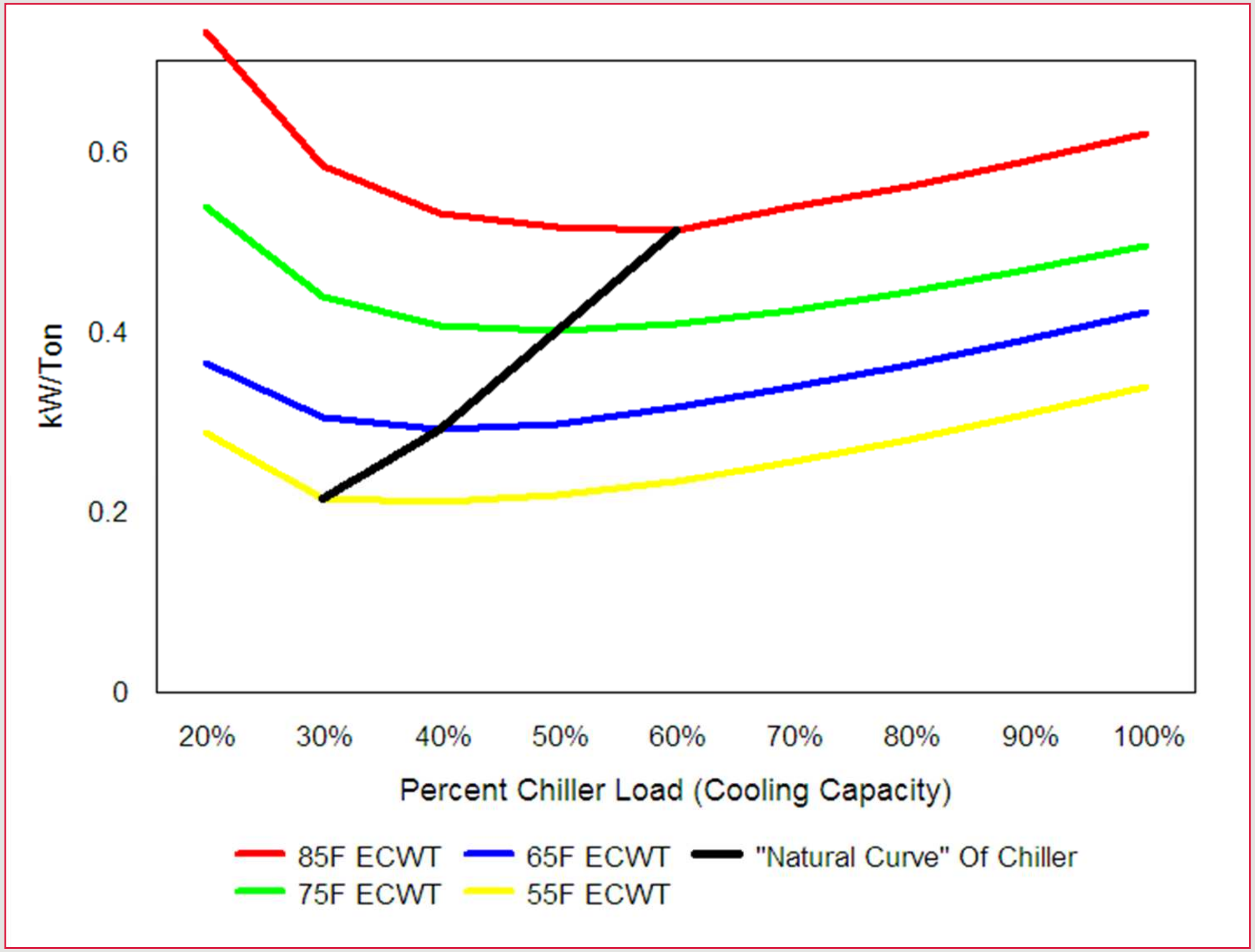
Variable Speed Devices are More Efficient at Part Load by Design Intent



"Natural Curve" of VS Centrifugal Chiller

"Natural Curve" of a Chiller

To achieve optimum performance, chillers should be sequenced such that the on-line chillers operate as close as possible to their Natural Curve.

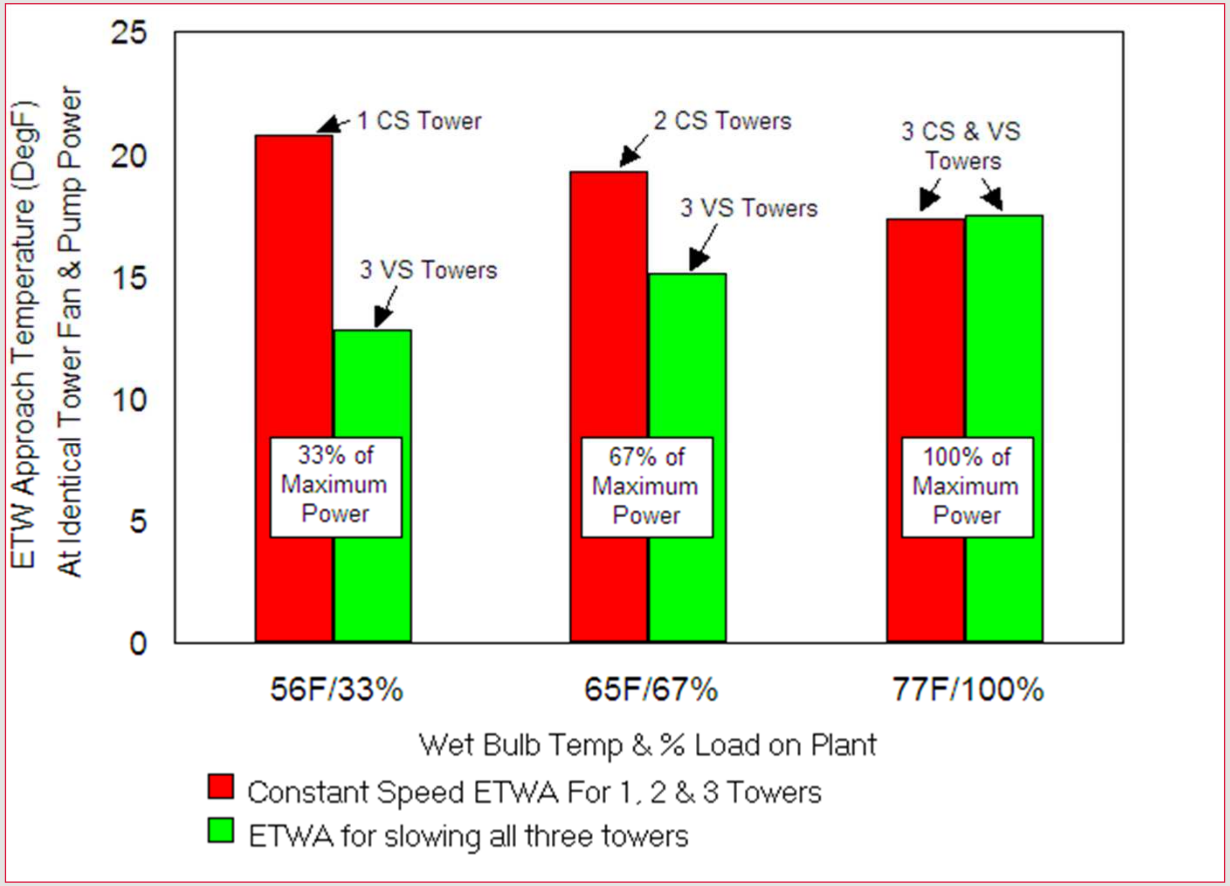


Tower ETW Approach Temperature For 3 Tower Systems

Natural Curve

Effect with Variable Flow and Fan Speed Tower

The total power to fans and pumps is the same for the variable speed and constant speed systems at each condition. Note the improved approach by slowing, not shedding towers at low loads.



Lower approach temperature provides the opportunity to operate on the lower curves on the previous slide (ie higher chiller eff.)

"Natural Curve" of VS Centrifugal Chiller With Variable Flow Towers

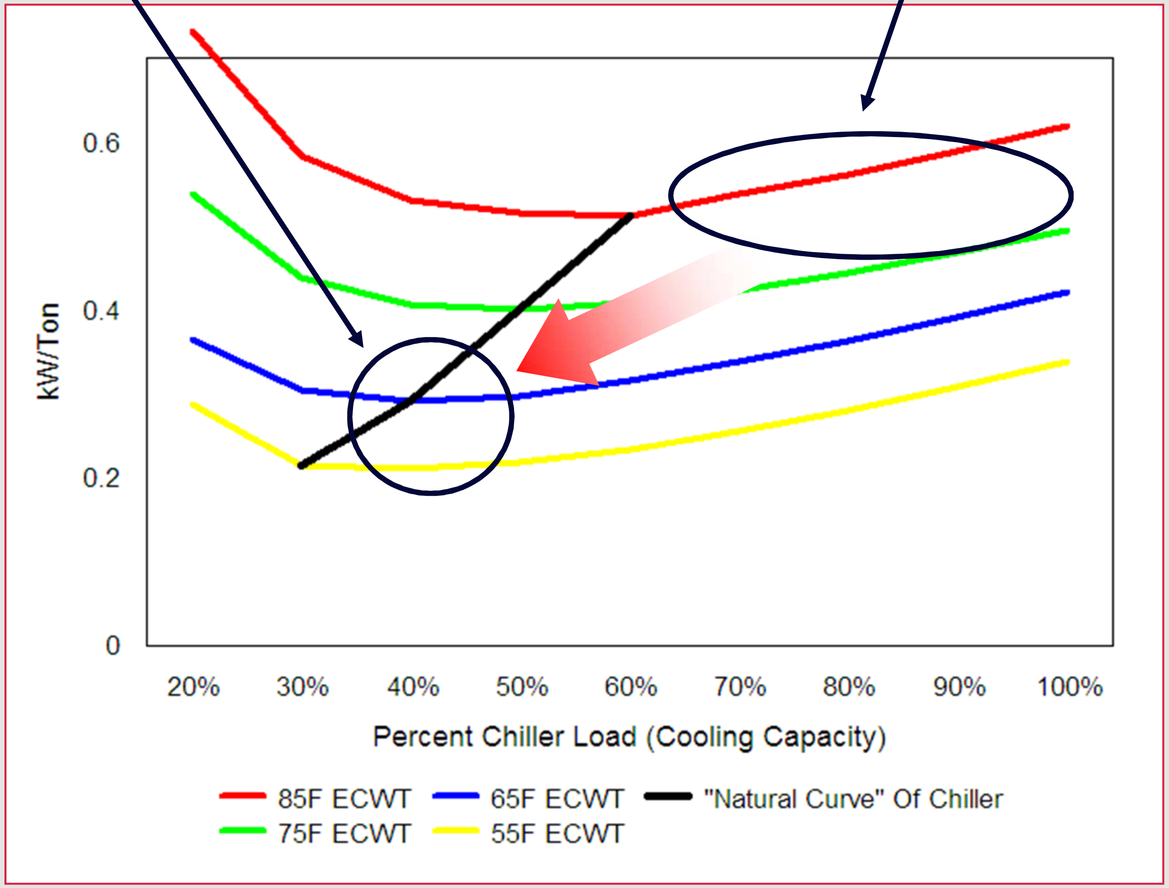
"Natural Curve" of a Chiller

For part load applications, we move from the top right to the bottom left.

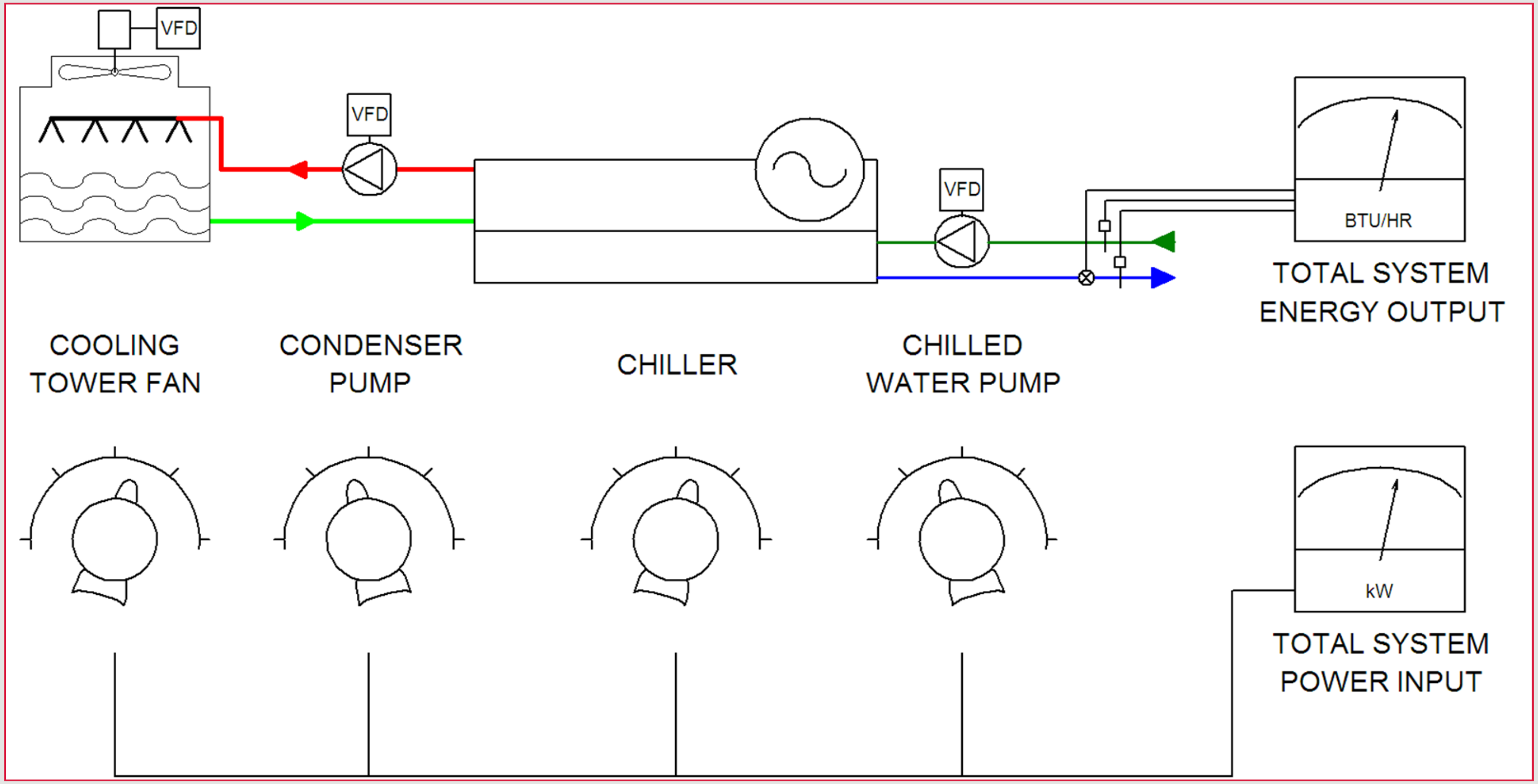
WOW!

IPC system operate chillers In this range during part load

Traditional control operates chillers in this range



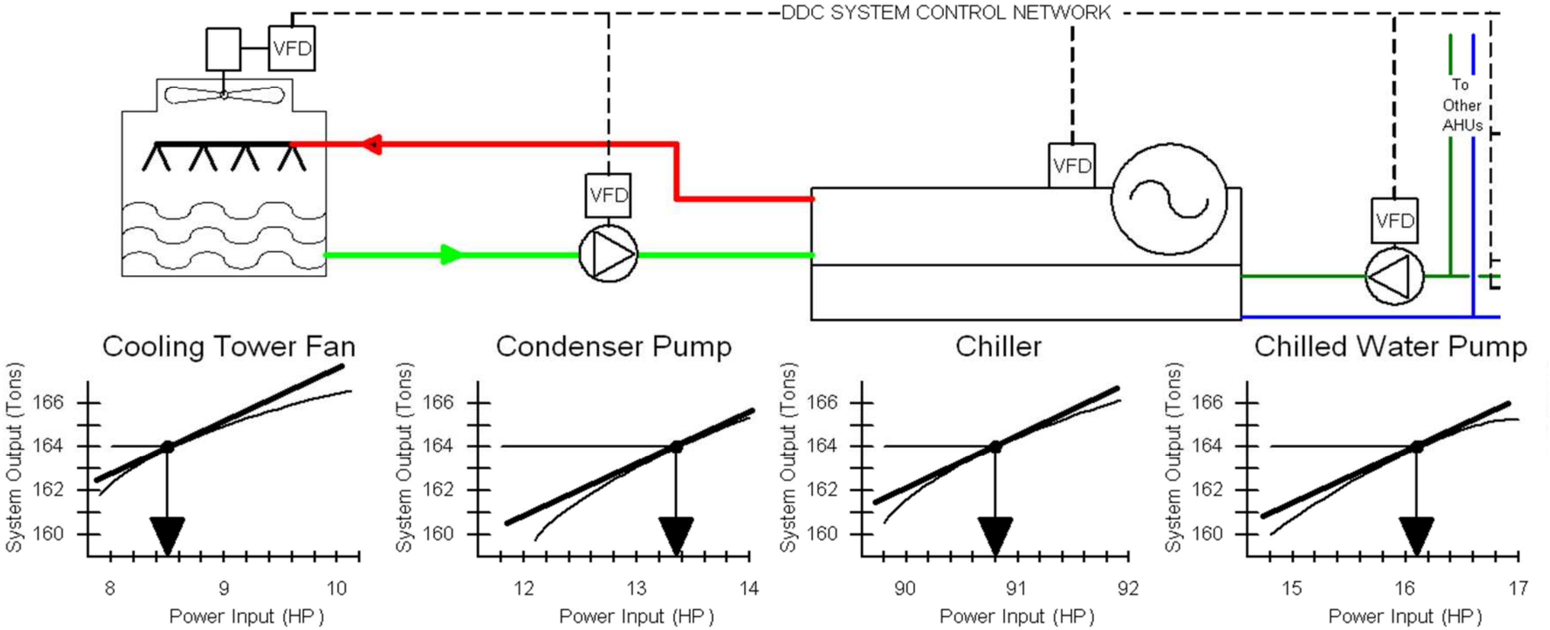
Optimizing All-Variable Speed Configurations: The "Equal Marginal Performance Principle"



Trade off equipment loading in one device to pick up more load on another, and achieve the same net “kW cooling” for lower kW electrical input.

Equal Marginal Performance Principal
"Optimal Net Efficiency"

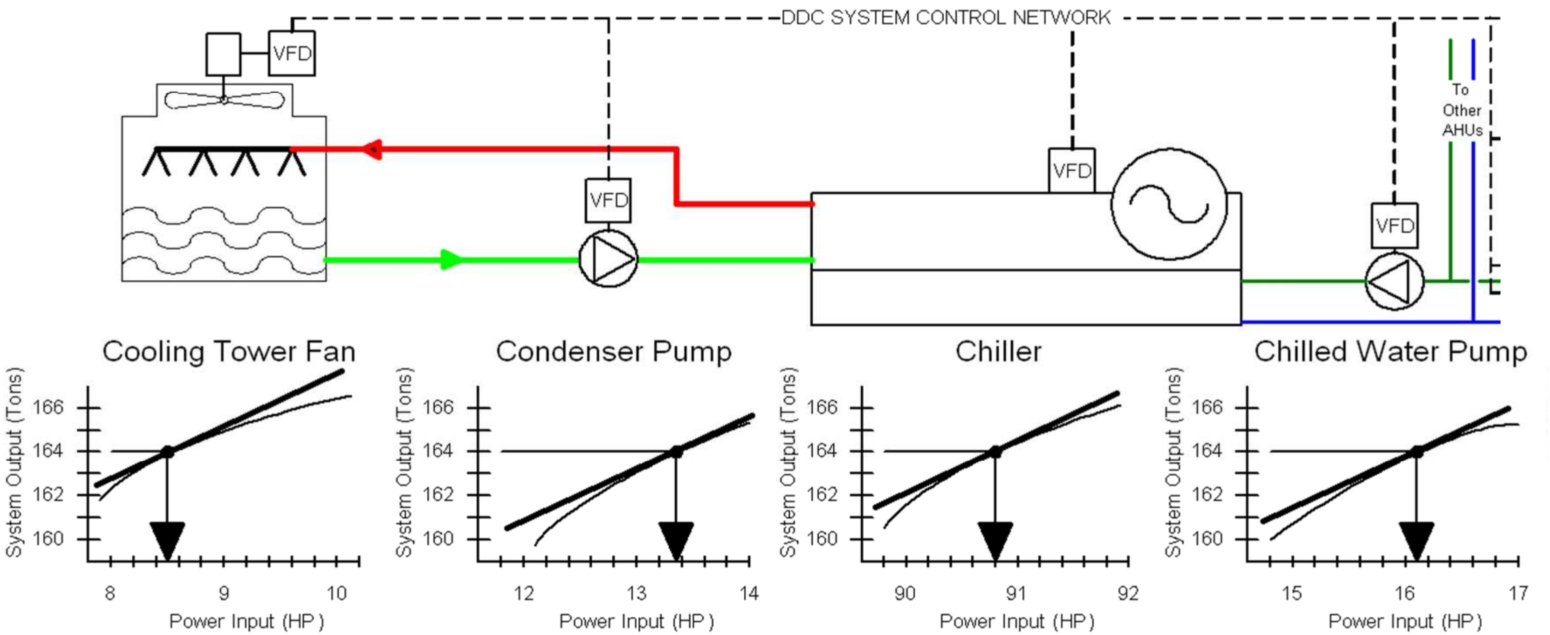
temperature or pressure setpoints.



Because continuous error correction is not an essential element of demand based control, operating stability is almost never an issue. The above system is optimized at the relative power settings shown by the arrows because, in accordance with the Equal Marginal Performance Principle, the marginal performance (slope of the curve of total system output per unit input for the component) is the same for all system components.

Demand Based Control
"Optimal Power Relationship Calculated"

temperature or pressure setpoints.



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Demand Based Control

An example of how the controller patented algorithm operates.

- Building load determines the distribution pump speed and flow (traditional pump speed control).
- The VS chiller has CHW supply temperature setting (say 44F), and will speed up or slow down based on the impact of flow change by the VS pumps (chiller control panel).
- If the chiller load changes then the IPC will increase or decrease the tower fan and or pump speed in accordance to the equal marginal performance principle based on the Demand Based Control relationships calculated for the plant equipment.
- The chiller load change has a dead band input to tower fan and pump speed to prevent continuous change / hunting.
- The relationship between tower fan and pump speed to chiller load is calculated by the Hartman LOOPTM methodology, if the chiller speed goes below or above Natural Curve the plant will stage up or down.
- The CHW supply temperature setpoint is adjusted based on the building load, for example between 38F – 52F, trading distribution pump power for compressor power.

Variable Primary/Variable Secondary Systems

- Different loop temperatures required
- District Cooling - secondary pumps in remote buildings

Example

- 2000 Ton Chilled Water Plant
- 1500 Hours – Annual Operation
- $.10 kWh

.80/kW/Ton

Annual Operating Cost - $240,000
25 Year Operating Cost = $6,000,000

.55 kW/Ton

Annual Operating Cost =$165,000
25 Year Operating Cost = $4,125,000

Savings = $1,875,000

Summary

Notre avenir vert vous appartient . . .
soyons intentionels

A Green Future is ours . . . .

Let’s be intentional about it

Ultra Efficient Chiller Plants . . .

Question & ANswers.