# Central Plant Air Systems: Keeping the Heart and Lungs Healthy

Better Buildings Summit
May 2016

U.S. DEPARTMENT OF ENERGY

# Introductions

**Michael Deru**
National Renewable Energy Laboratory

New Resources

**Mark Hydeman**
Continual, Inc.

ASHRAE Guideline 36

**Michael Ivanovich**
AMCA

Fan value with AMCA

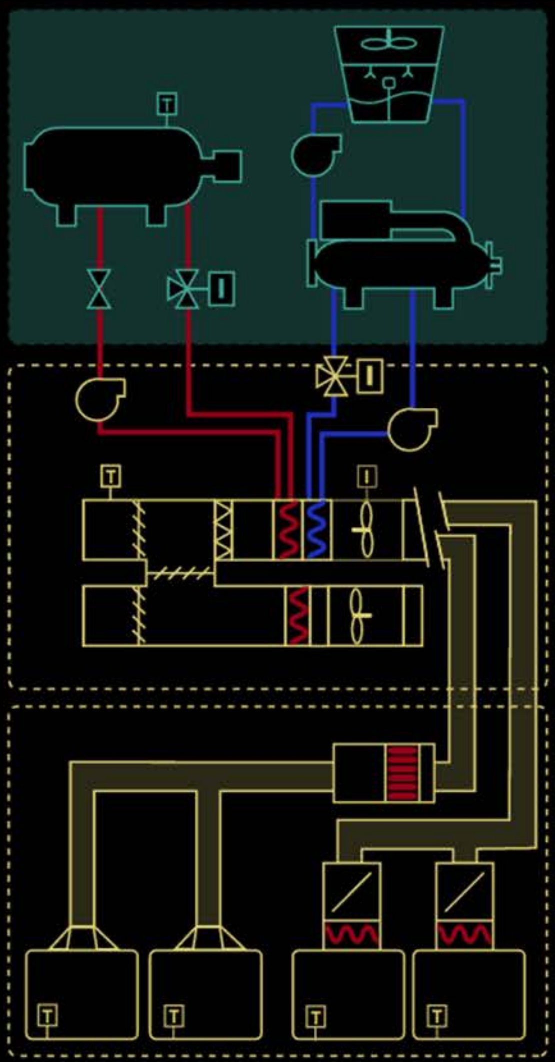
**Steve Dikeman**
AcoustiFLO, LLC

Getting the most of your fans

# Central Plant Resource Map

## HVAC Resources

- HOME
- CENTRAL PLANT
- DISTRIBUTION SYSTEM
- SPACE LOADS



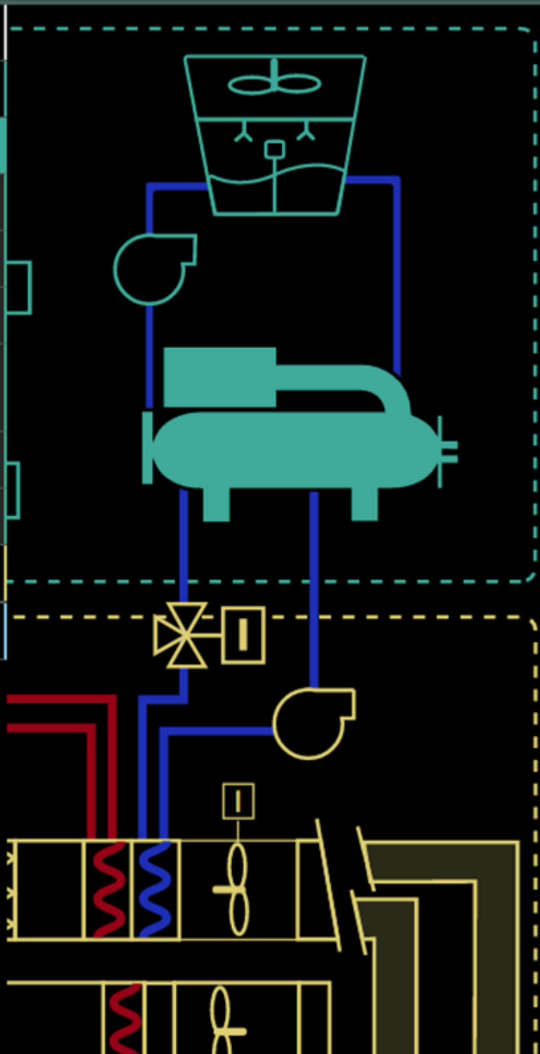
### CENTRAL PLANT

Chilled Water Central Plants typically concise of chiller(s), chiller water pump(s), condenser water pump(s), cooling tower(s), water treatment system, controls, and energy metering. Typically chilled water central plants supply systems with cooling loads in excess of 50 tons that can range from one building to a campus of buildings. Use of cooling towers versus air cooled condensers found in smaller stand alone HVAC systems can save energy by using wet bulb temperatures versus drive bulb temperatures to reject heat from the cooling system. The added components in these systems adds to complexity of operations and a higher level of operator knowledge and control oversight than stand alone HVAC systems.

# Central Plant Resource Map

**HVAC Resources**

- HOME
- CENTRAL PLANT
- Chiller
- Boiler
- Cooling Tower
- Pump
- Thermal Energy Storage
- Sensors & Controls
- Cogeneration Design
- DISTRIBUTION SYSTEM
- SPACE LOADS



# Chiller

- General Info
- Types
- Codes & Standards
- Design Guides & EEMs
- Calculators & Tools
- Operation & Training
- Procurement & Performance
- Case Studies

## General Description and Uses

Chillers and air conditioners use one or more forms of energy to move thermal energy from one place to another thereby making one side colder and the other side hotter. Most chillers are based on using mechanical work with a working fluid (the refrigerant) to move thermal energy; however chillers can also be chemical, thermoelectric, thermoacoustic, or magnocaloric.

Vapor compression based chillers or refrigeration systems are based on moving a working fluid or refrigerant around a cycle comprised of four main components: compressor, condenser, expansion device, and evaporator. The compressor moves the refrigerant around the cycle and adds work (energy) to the vapor phase of the refrigerant by compressing it. The condenser rejects the heat from the hot vapor and condenses the refrigerant to a liquid. The expansion device allows a controlled expansion of the "hot" liquid refrigerant, which lowers its temperature and the evaporator is used to transfer heat from the area that is being cooled to the refrigerant.

## Commonly Used Terms

***IPLV (Integrated part-load value):*** A single-number figure of merit based on part-load EER, COP, or kW/ton expressing part-load efficiency for air-conditioning and heat pump equipment on the basis of weighted operation at specific increments of load capacities for the equipment. Typically used for ARI rating purposes. *Source: ASHRAE Terminology*

***NPLV (Nonstandard part-load value):*** A single-number part-load efficiency figure of merit calculated and referenced to conditions other than IPLV conditions for units that are not designed to operate at ARI standard rating conditions. *Source: ASHRAE Terminology*

# How Well are Your Systems Performing?

## End Use Energy Performance Targets

| Inputs | |
|---|---|
| Building type | Large Office |
| Reporting units | kBtu/ft2/yr |
| Zip code | 90210 |
| County | Los Angeles |
| State | CA |
| Climate zone | 3B-coast |

In the "Inputs" box:
- Select the building type from the drop-down list.
- Select the desired reporting units in kBtu/ft²/yr, kWh/ft²/yr, MJ/m²/yr, or kWh/m²/yr.
- Enter the zip code.
- Verify that the county and state correspond to the building location.

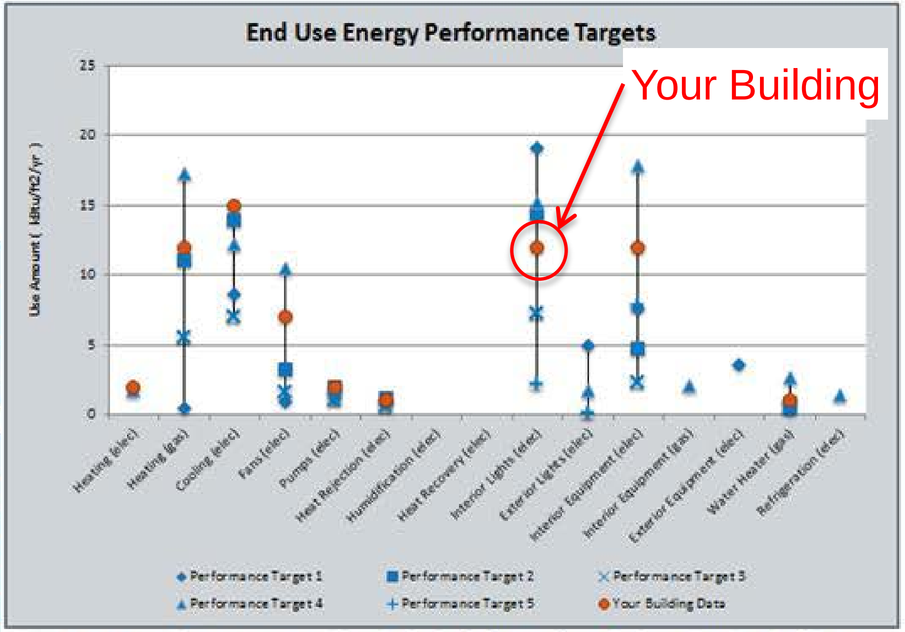
See the following tables for the specific information. Enter the building data in the white cells in the last column.

| Data Details | Performance Target 1 | Performance Target 2 | Performance Target 3 | Performance Target 4 | Performance Target 5 | Your Building |
|---|---|---|---|---|---|---|
| Data sources | DOE Reference Building | 50% TSD Baseline | 50% TSD Low Energy | CEUS | NREL Simulation | Acme Office |
| Data type | Simulation | Simulation | Simulation | Calibrated Simulation | As-Built Simulation | Sub-meter |
| Hours of operation (hours/week) | 101.00 | 97.00 | 97.00 | N/A | N/A | 95.00 |

| HVAC | Performance Target 1 | Performance Target 2 | Performance Target 3 | Performance Target 4 | Performance Target 5 | Your Building |
|---|---|---|---|---|---|---|
| | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr |
| Heating (elec) | 0.00 | 0.00 | 0.00 | 1.67 | ND | 2.00 |
| Heating (gas) | 0.47 | 11.00 | 5.50 | 17.22 | ND | 12.00 |
| Cooling (elec) | 8.59 | 13.90 | 7.00 | 12.18 | ND | 15.00 |
| Fans (elec) | 0.95 | 3.20 | 1.60 | 10.44 | ND | 7.00 |
| Pumps (elec) | 1.11 | 2.00 | 1.00 | 0.00 | ND | 2.00 |
| Heat rejection (elec) | 0.92 | 1.10 | 0.60 | 0.00 | ND | 1.00 |
| Humidification (elec) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Heat recovery (elec) | 0.00 | 0.00 | 0.00 | 0.00 | ND | |

| Lighting | Performance Target 1 | Performance Target 2 | Performance Target 3 | Performance Target 4 | Performance Target 5 | Your Building |
|---|---|---|---|---|---|---|
| | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr |
| Interior lights (elec) | 19.08 | 14.40 | 7.20 | 15.22 | 2.16 | 12.00 |
| Exterior lights (elec) | 4.95 | 0.00 | 0.00 | 1.67 | 0.12 | 0.00 |

| Process Loads | Performance Target 1 | Performance Target 2 | Performance Target 3 | Performance Target 4 | Performance Target 5 | Your Building |
|---|---|---|---|---|---|---|
| | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr | kBtu/ft2/yr |
| Interior equipment (elec) | 7.58 | 4.70 | 2.30 | 17.81 | 7.84 | 12.00 |
| Interior equipment (gas) | 0.00 | 0.00 | 0.00 | 2.10 | 0.00 | 0.00 |
| Exterior equipment (elec) | 3.58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |




The End Use Energy Performance Targets graph shows the bands of performance for each end use. The values at the higher bounds represent the baseline values; the lower value solutions represent buildings that have better practices in that specific end use.

Compare your building end uses to a range of standard benchmarks

Michael Ivanovich, AMCA
Steve Dikeman, AcoustiFLO, LLC

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# How to Save Energy in Air Systems

## *Presented by*

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# Learning Objectives

**Ivanovich**

- About AMCA
- System Effect

**Dikeman**

- System Leakage
- Right-Sizing Fans

# What is AMCA?

- Air Movement and Control Association International, founded in 1917
- Not-for-profit manufacturers association of fans, dampers, louvers and other air movement and control products
- Mission is to promote the health, growth and integrity of the industry

# What is the AMCA Certified Ratings Program?

**How AMCA's Certified Ratings Program works:**

- Companies send products to AMCA for testing
- AMCA tests products for parameters specified
- AMCA checks its data against manufacturer literature

**After certification, the product**

- Is licensed to bear AMCA's seal
- Is listed in AMCA's online database
- Undergoes check tests every three years

# System Effect: 1ST Definition

*Installed duct configuration does not match tested duct configuration*

# System Effect: 2nd Definition

*Even when the tested duct configuration matches the installed duct configuration, improper duct design can introduce adverse flow conditions*

# Rules of Thumb

- Minimum 2.5 duct diameters on outlet
- Minimum 3 to 5 duct diameters on Inlet
- Avoid inlet swirl

# Recommendations

1. *Allow enough space in the building design for fan connections*
2. *Use allowances in design calculations when space is a factor*
3. *Reference AMCA 201*
4. *Include allowance for the effect of all accessories and appurtenances*

# System Leakage

- Establish level of tightness needed
- Specify air system components and sealants that perform together as a system
- Select a testing standard that ensures the leakage objective is met

**2012 ASHRAE Handbook—HVAC Systems and Equipment** and **2013 ASHRAE Handbook—Fundamentals**

# Right Sizing Fans

- Efficient
- Quiet
- Cheap

…Select any two!

# Constant Speed Air Systems

- Variable volume air systems = variable speed systems
- Constant volume systems with variable pressures = variable speed systems
- Night setback, after hours, weekend modes are candidates for variable speed
- Constant speed air systems are neither constant volume or constant pressure

# Variable Speed Air Systems

Minimal reduction in speed offers a massive reduction in input power

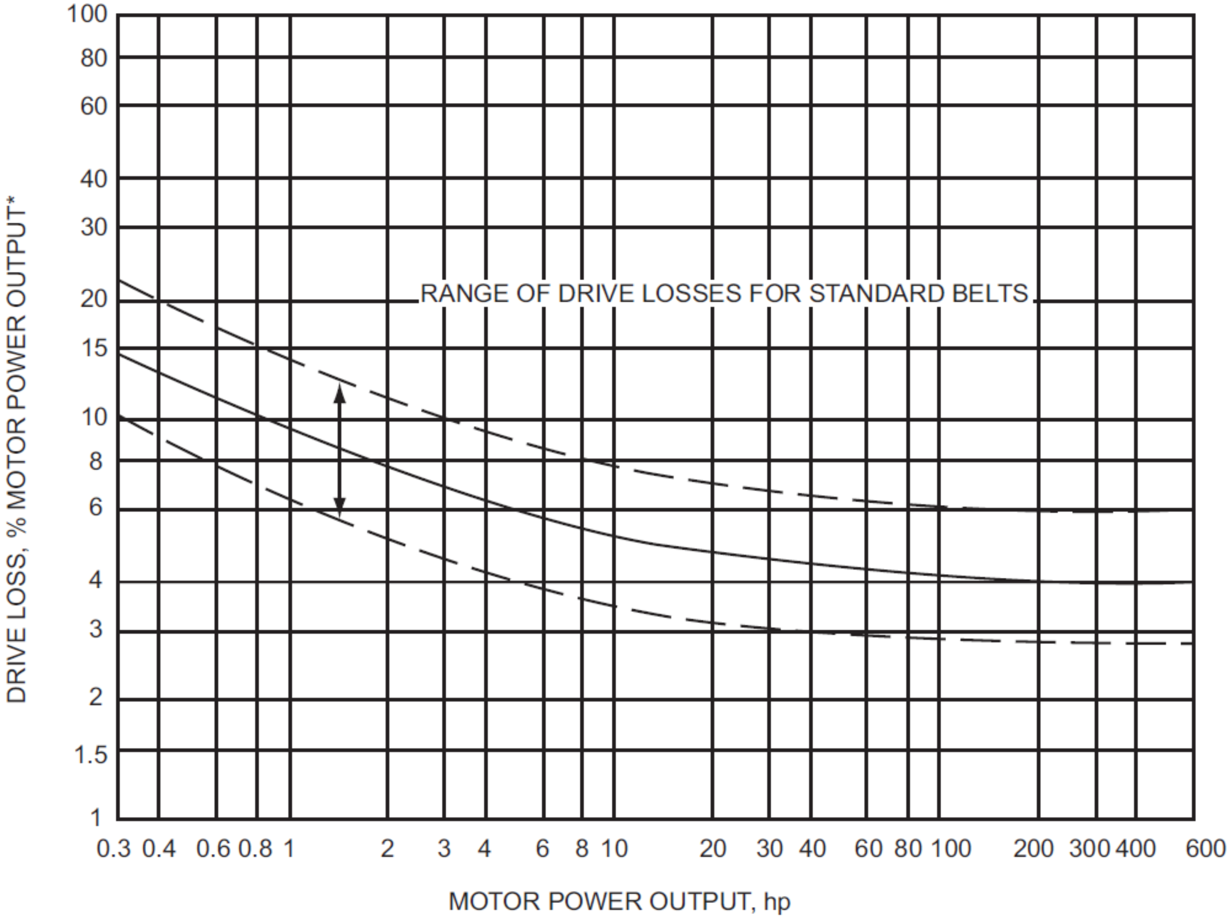
- 90% speed → 73% impeller bhp
- 80% speed → 50% impeller bhp
- 70% speed → 34% impeller bhp
- 60% speed → 22% impeller bhp

# Design Wheel Speed

- For every duty point, there is an optimum wheel speed.
- Pulleys and belts
- Direct drive
- No belts and speed control!

# Belt Loss

AMCA 203-90 (R2007)




3% to 10%
4% to 15%
6% to 22%

# Right-Sizing Fans

- Design flow
  (includes a safety factor)
- Design pressure
  (includes a safety factor)
- Filter loading
  (all filters at the same time)
- Plus another safety factor?
- Input flow and pressure into selection software

# Right-Sizing Fans

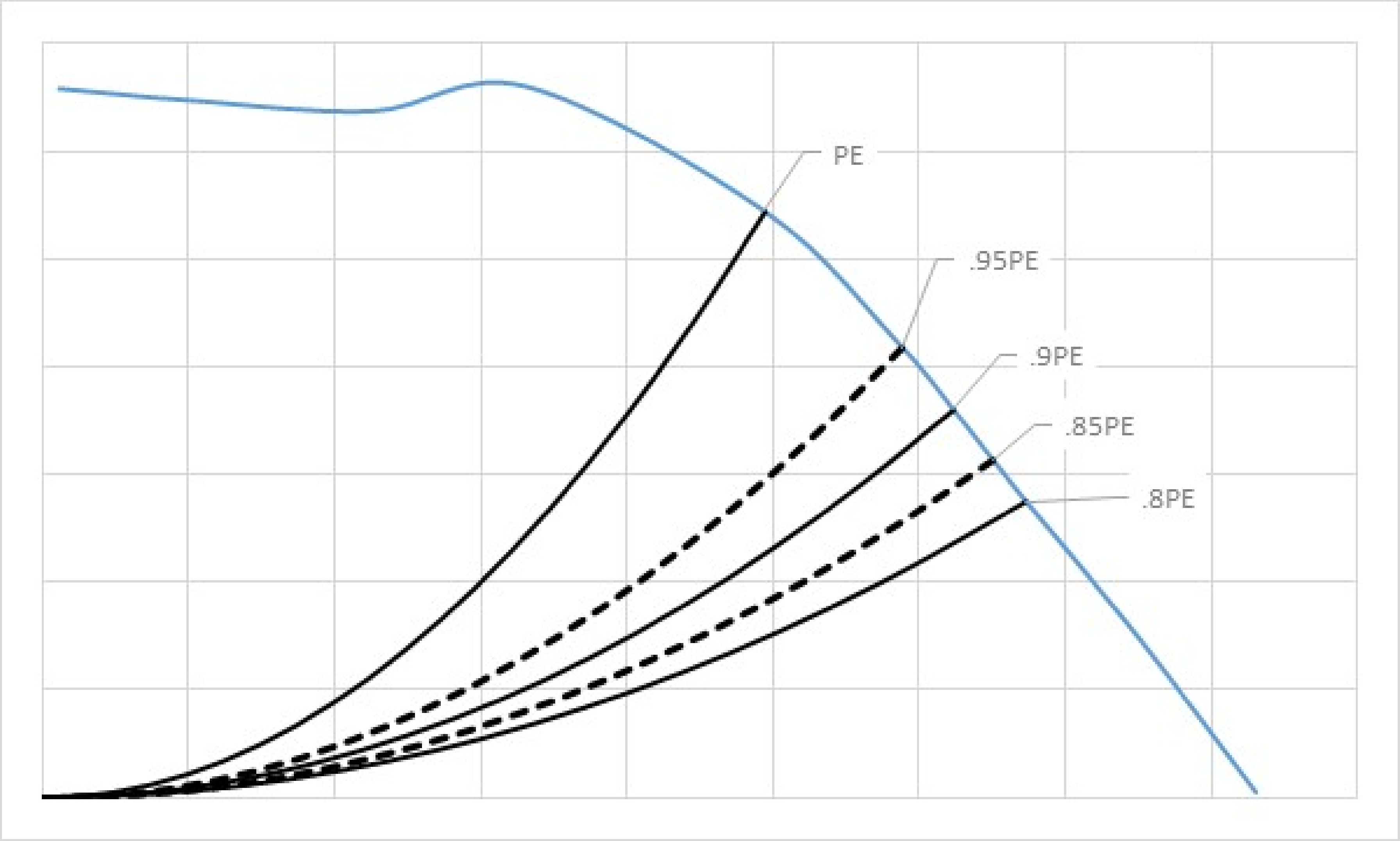
| Fan diameter (inches) | Input power (bhp) |
|---|---|
| 30” | 10.2 |
| 27” | 10.3 |
| 24” | 10.7 |
| 22” | 11.9 |
| 20” | 14.4 |

All selections require a 15 HP motor. Unless input power is defined which wheel will you get? – the cheapest/smallest

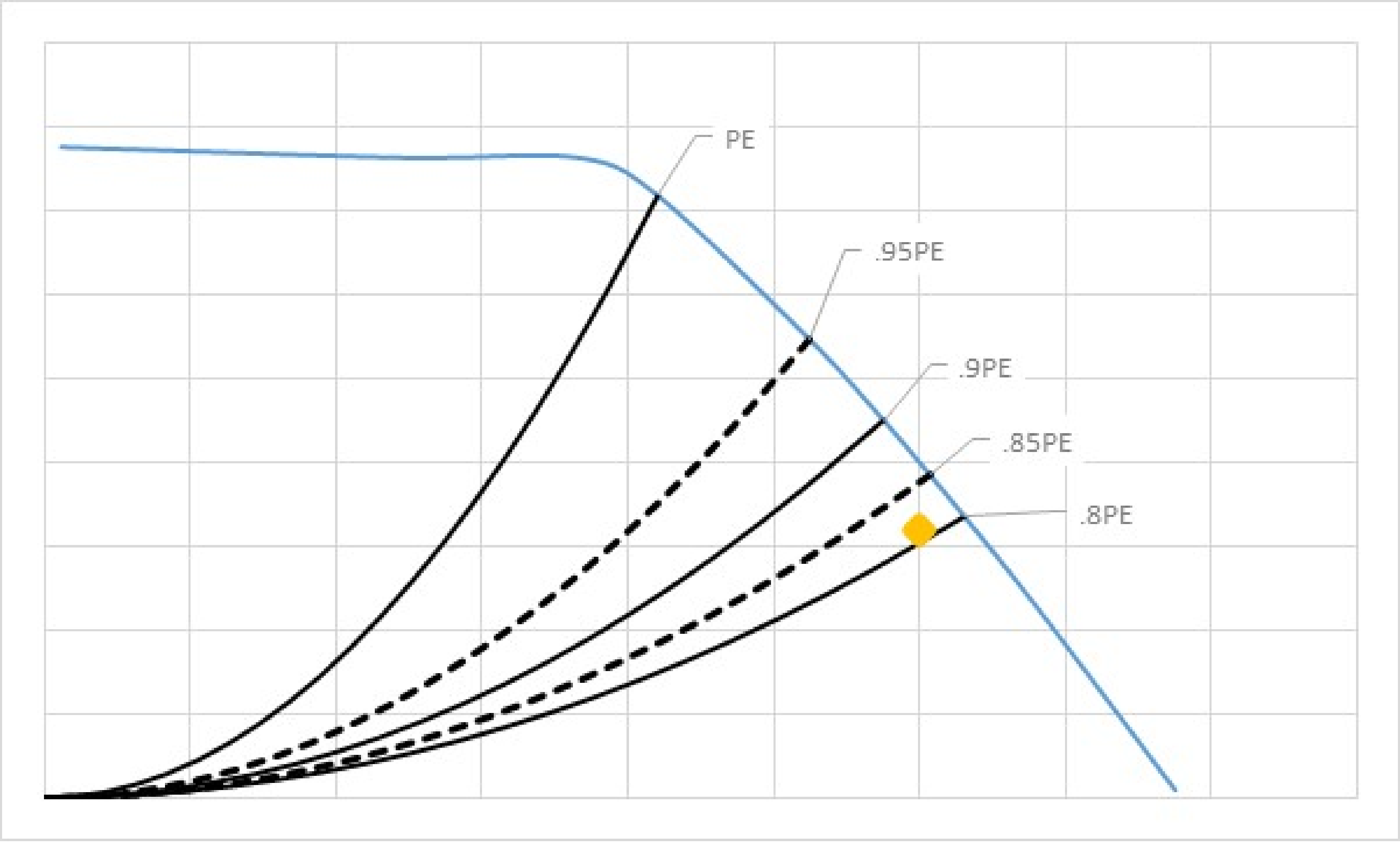
A 42% difference in energy consumption

“It’s only 4.2bhp” (12,000cfm at 4”)

# Fans are Simple Machines

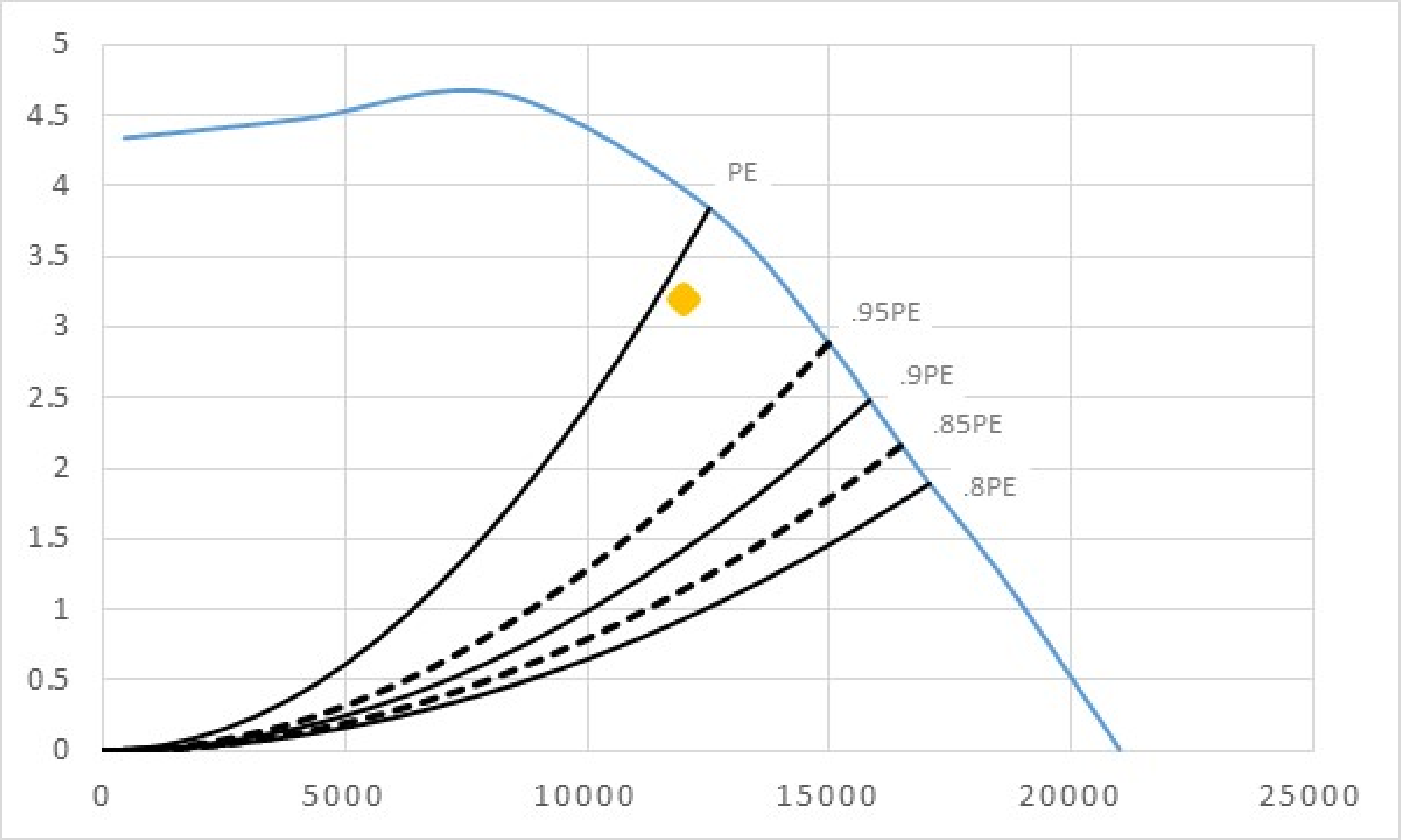


# Fans are Simple Machines




The smallest wheel – design flow & 80% pressure.
Fan efficiency down yet another 5% from the selection point

# Fans are Simple Machines




Largest wheel – design flow & 80% pressure.
Still near design efficiency

# Right-Sizing Fans

- Imperative to specify a maximum absorbed power
- “Bigger wheel” minus “slower speed” isn’t always better
- For VAV supply fans, reset minimum pressure set point
- Evaluate the fan curve, not just the tabular output

Mark Hydeman
Continual, Inc.

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# ASHRAE Guideline 36P Best of Class Sequences for HVAC Systems

Speaker: Mark Hydeman, PE, ASHRAE Fellow
Chair of GPC 36 (and Principal Investigator for RP-1455)

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Presentation Agenda:

- Overview of Guideline 36P
- How GPC 36P Will Improve The Industry
- How To Get Involved

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# About Continual Energy Inc.

Continual Energy Inc. solves your most critical building energy needs. From HVAC system optimization technology, to engineering studies, performance guarantees and financing to monitoring based commissioning technology, we deliver and sustain energy and cost savings across various building applications.

Philip Kennedy
Principal, Toronto

Jason Zwicker
Principal, Toronto

Josh Kahan
Principal, Montreal

Mark Hydeman
Principal, California

Dr. Alex Lee
Sales, Singapore

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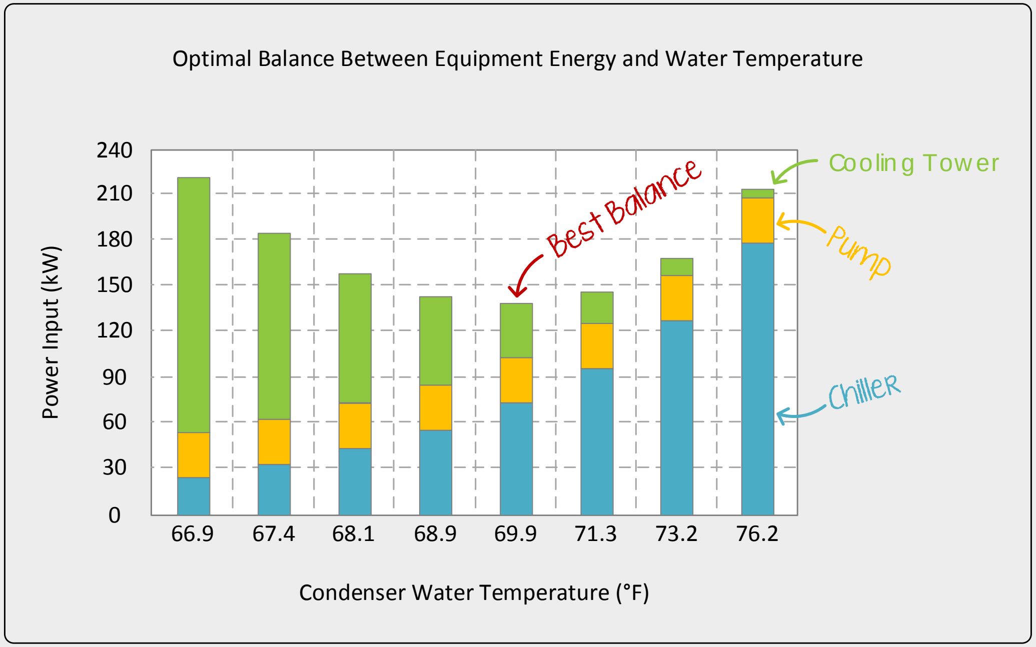
# About Continual Energy Inc.

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# Guideline 36 Overview

- ASHRAE Guideline Project Committee 36 was created to disseminate, support and further develop advanced HVAC sequences including RP-1455 and future related research projects from ASHRAE TC 1.4
  - **Title:** **High Performance Sequences of Operation for HVAC Systems**
  - **Purpose:** Provide uniform sequences of operation for heating, ventilating, and air-conditioning (HVAC) systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and allow real-time fault detection and diagnostics.
  - **Scope:**
    - This guideline provides detailed sequences of operation for HVAC systems.
    - This guideline describes functional tests that when performed will confirm implementation of the sequences of operation.
- Public website for ASHRAE GPC 36: http://gpc36.savemyenergy.com/

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# Guideline 36 Overview

- Create best of class sequences of operation and corresponding functional test scripts that meet or exceed the requirements of ASHRAE Standards:
- Long term goal of Guideline 36
  - Manufacturers preprogram and debug all the sequences for their dealers
  - Engineers modify as appropriate for their projects
    - Perhaps with special adjustments unique to project
  - Control contractors simply use the preprogrammed sequences, adjusted where specified.
  - Commissioning agents use the functional performance tests included w/Guideline 36


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# Guideline 36 Timeline

- First meeting June 2014
- First Draft (dry-side only) went out for Advisory Public Review in June 2015: 14 Commenters,  114 Comments.
- Voted for Publication Public Review in April of 2016.


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# Guideline 36 Current Scope (RP-1455)

- Includes sequences for air systems (dry-side)
- Sections:
  - General logic (e.g. zone groups, zone mode, alarms, etc.)
  - Terminal Units: VAV(cooling-only and reheat), DDVAV & FCUs
  - AHUs & ACUs (single and multiple zone)
- Sequences developed and simulation tested in real control hardware under ASHRAE Research Project RP1455.
  - A new research project was just approved to field test these SOOs and develop companion FPTs.

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# Objectives

- Reduce Cost
  - Writing sequences, programming, and commissioning
- Reduce Errors
  - Unambiguous English-language sequences
  - Algorithms pretested and standardized
  - The GPC 36 committee will keep the document up to date
- Improve Energy Efficiency
- Improve Code and Standard Compliance
  - ASHRAE Standards 90.1 (energy efficiency),
  - 62.1 (ventilation), and
  - 55.1 (thermal comfort)
- Incorporate best of class performance (next slide)

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# Innovations in GPC 36P

- Application of trim and respond controls for resets
- Automatic fault detection and diagnostics (AFDD) based on NIST Research
- Hierarchical alarm suppression
- Controls algorithms programmed and simulation tested in real control hardware
- Both written sequences and functional logic block representations are available
- Sequences include embedded application notes and examples.

★ = covered later


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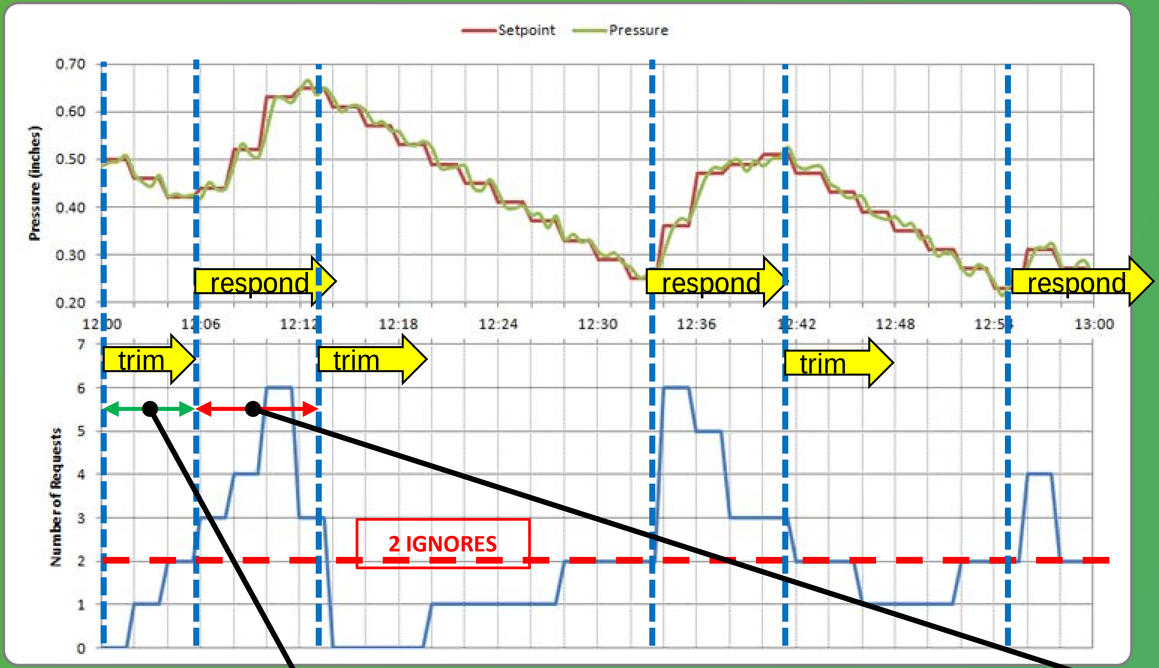
# Trim & Respond Example: Supply Pressure from VAV Box Requests (2 ignores and 1 request for each VAV box with cooling loop ≥ 90%)




Trim when requests are less than ignores, and respond when requests are more than ignores

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# T&R Rogue Zones

- A rogue zone is one that is always requesting more (more static pressure, colder CHW, or hotter HHW)
  - Example causes:
    - Load added to a zone or removed with no change to the terminal unit size or settings
    - Starved zones due to inadequate air or hydronic distribution
    - Undersized fans, coils, pumps, etc.
    - Extreme set-point adjustments, and
    - Equipment failure (broken damper, valve)
    - No commissioning or items not caught in the “commissioning”
- This drives the reset loop to extremes and prevents energy savings.
- You can alarm on request-hours (following slides)

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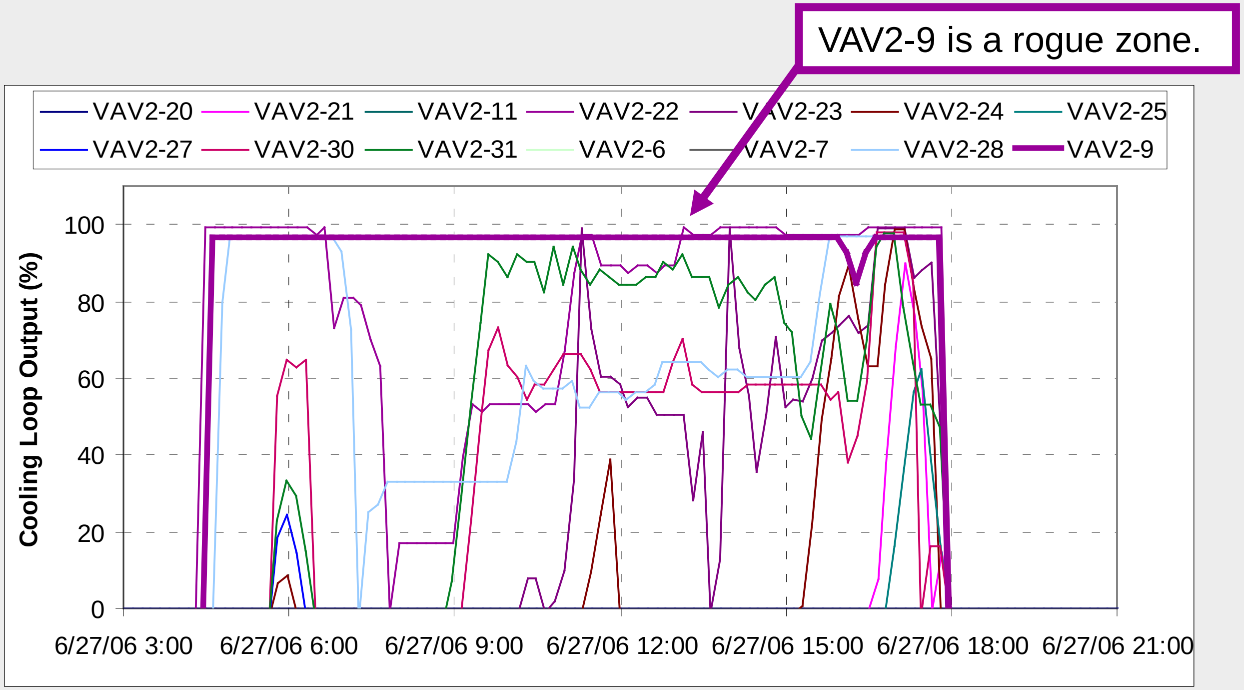
# General Logic: T&R Rogue Zones




Rogue zones can be automatically detected by alarming on request-hours.



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# General Logic: Trim and Respond Parameters

For each upstream system or plant setpoint being controlled by a T&R loop, define the following variables. All variables below shall be adjustable from a reset graphic accessible from a hyperlink on the associated system/plant graphic. Initial values are defined in system/plant sequences below. Values for trim, respond, time step, etc. shall be tuned to provide stable control.

| Variable | Definition |
|---|---|
| $SP_0$ | Initial setpoint |
| $SP_{min}$ | Minimum setpoint |
| $SP_{max}$ | Maximum setpoint |
| $T_d$ | Delay timer |
| T | Time step |
| I | Number of ignored requests |
| R | Number of requests from zones/systems |
| $SP_{trim}$ | Trim amount |
| $SP_{res}$ | Respond amount (must be opposite in sign to $SP_{trim}$) |
| $SP_{res\text{-}max}$ | Maximum response per time interval (must be same sign as $SP_{res}$) |



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# General Logic: T&R Rogue Zones

Finding rogue zones requires operator attention.

BAS calculates Request-Hours for each zone, and alarms on high cumulative %-Request-Hours.

*Request-Hours accumulates the integral of requests (prior to adjustment of Importance Multiplier) to help identify zones/systems that are driving the reset logic. Rouge zone identification is particularly critical in this context, since a single rouge zone can keep the Trim & Response loop at maximum, and prevent it from saving any energy.*

b) Request-Hours. Every x minutes (default 5 minutes), add x/60 times the current number of requests to this request-hours accumulator point. The request-hours point is reset to zero upon a global command from the system/plant serving the zone/system – this global point simultaneously resets the request-hours point for all zones/systems served by this system/plant.

c) Cumulative%-Request-Hours. This is the zone/system Request-Hours divided by the zone/system run-hours (the hours in any Mode other than Unoccupied Mode) since the last reset, expressed as a percentage.

d) A Level 4 alarm is generated if the zone Importance Multiplier is greater than zero, the zone/system Cumulative%-Request-Hours exceeds 70%, and the total number of zone/system run-hours exceeds 40.

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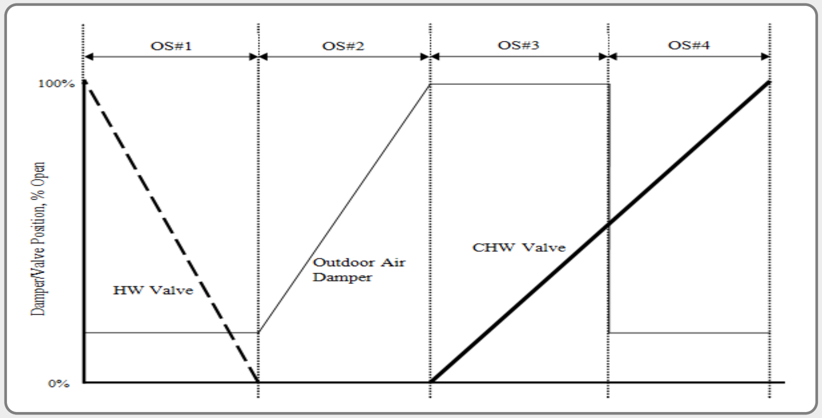
# AFDD: Automatic Fault Detection & Diagnostics

- Based on research by House, Bushby and Schein at NIST in 2000-2006.
- Only adopted for air handlers (APAR) in GPC 36P. VAV box FDD (VPACC) requires too much tuning.
- Finds fault and diagnosis by evaluating equations (mostly energy balance).




| | | | |
|---|---|---|---|
| FC #1 | **Equation** | $DSP < DSPSP - \varepsilon_{DSP}$ <br> and <br> $VFDSPD \geq 99\% - \varepsilon_{VFDSPD}$ | **Applies to OS** <br> **#1 – #5** |
| | **Description** | Duct static pressure is too low with fan at full speed | |
| | **Possible Diagnosis** | Problem with VFD <br> Mechanical problem with fan <br> Fan undersized <br> SAT Setpoint too high (too much zone demand) | |
| FC #2 | **Equation** | $MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$ | **Applies to OS** <br> **#1 – #5** |
| | **Description** | MAT too low; should be between OAT and RAT | |
| | **Possible Diagnosis** | RAT sensor error <br> MAT sensor error <br> OAT sensor error | |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# Hierarchical Alarm Suppression

- A VAV reheat box has three sources of up-steam control:
  - Air pressure
  - Air temperature, and
  - Reheat coil source (electric or hot-water)
- If the upstream source is in alarm (e.g. the AHU fan trips) the zone temperature alarms are suppressed.
- In the zone alarm logic you disable the cooling alarm if the upstream source (fan, DX unit or chiller) has tripped.

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# Related ASHRAE Research

- RP-1587 Control Loop Performance Assessment (complete)
- RP-1746 Field Validation of RP-1455 and development of FPTs (awarded in December 2015)
- RP-1747 Implementation of RP-1547 CO2-based Demand Controlled Ventilation for Multiple Zone HVAC Systems (awarded in December 2015)
- WS-1711 Advanced Sequences of Operation for HVAC Systems – Phase 2 Central Plants and Hydronic Systems (approved for bid in Spring of 2016).

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- WS-1711 Advanced Sequences of Operation for HVAC Systems – Phase 2 Central Plants and Hydronic Systems (approved for bid in Spring of 2016).
- Kudos to Steve Taylor my ex-partner who had and executed the vision


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# Guideline 36 How to Get Involved

- If you are interested in participating in GPC 36, join monthly net meetings.
  - Generally the 2nd Thursday of the month from 8:00 AM to 12:00 PM PST (11:00 AM to 3:00 PM EST).
  - Meeting details on website: [http://gpc36.savemyenergy.com/](http://gpc36.savemyenergy.com/)


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# Thank you! Any questions?

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# Thank you!

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