The Perfect Economizer ; Looking for Shapes in the Clouds

Assessing an Economizer

Presented By:

David Sellers, Facility Dynamics Engineering

Senior Engineer

Looking for Shapes in the Clouds

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Looking for Shapes in the Clouds

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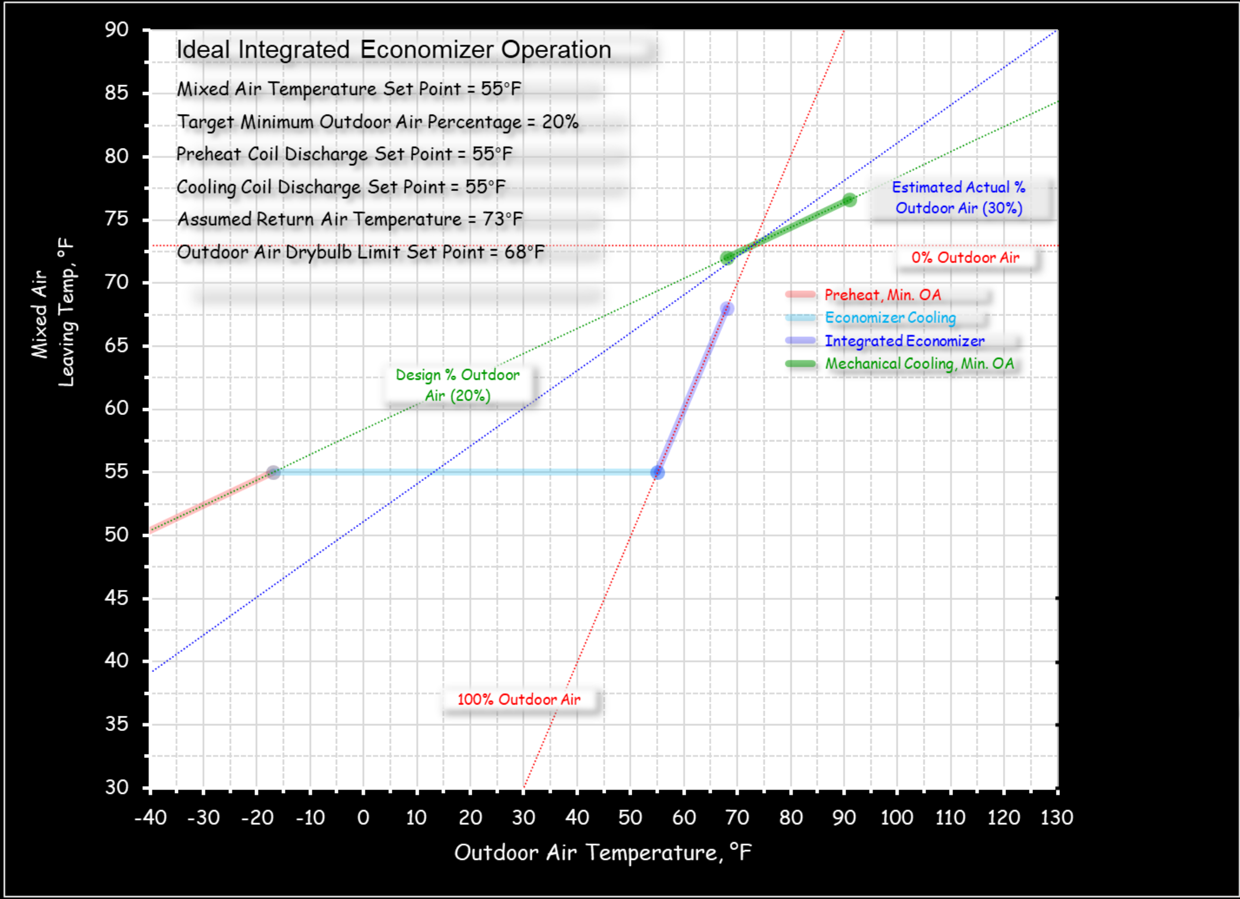
The Perfect Economizer Concept

- Not a new concept
- Plot mixed air temperature as a function of outdoor air temperature for an economizer that was working perfectly



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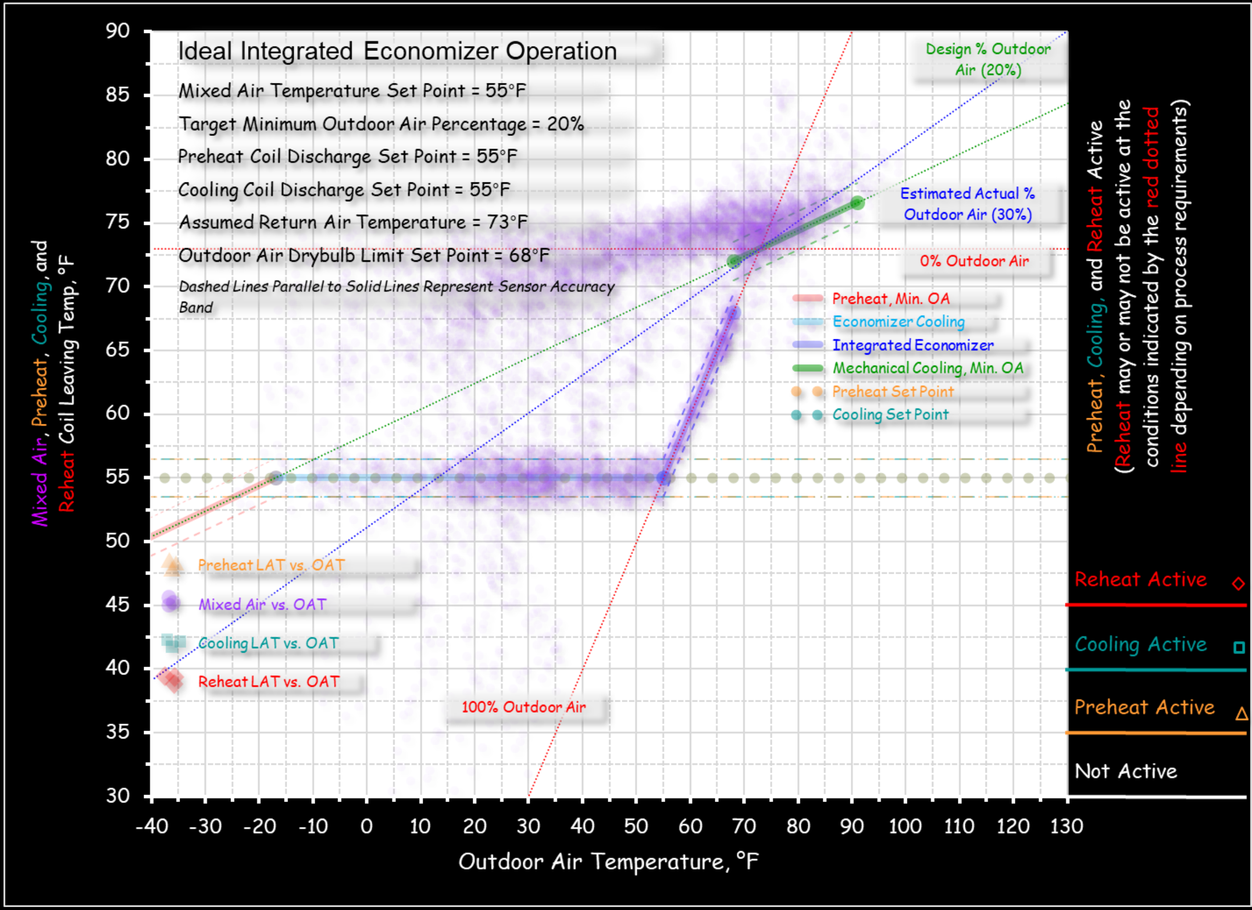
- Scatter plot actual mixed air temperature as a function of outdoor air temperature against it
- Look for shapes in the clouds



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More information at:

https://tinyurl.com/PerfectEconomizer


David Sellers

The Perfect Economizer

BY DAVID SELLERS, P.E., MEMBER ASHRAE

My previous column* in the October 2021 issue of *ASHRAE Journal* explored a technique that compares a chilled water plant's performance to perfection (*Figure 1*). Data from a near-perfect plant will create a cloud around the solid lines if plotted against them. A hazy blue cloud nowhere near the lines, like the areas outlined in red, yellow and green, indicates a potential problem. A common reason for the unnecessary chilled water use in the areas outlined in red and yellow is dysfunction in the preheat and economizer processes. Thus, the team I was working with at the facility decided to use a similar idea that I call "The Perfect Economizer Concept" to assess their air-handling units (AHUs).† That analysis technique is the focus of this column.

Nothing New

The "Perfect Economizer" concept is similar to the "Perfect Load" concept from my last column in that you create a chart that illustrates perfection and then plot real data against it to see how closely reality matches it.

The idea is not particularly new. For example, the (free) Universal Translator application§ includes a module that uses this approach.

This column will illustrate how the concept works, and how it can be used to perform diagnostics founded on field data. If I am successful, you should be able to take what I write and build a spreadsheet in Excel or similar application that will perform the analysis.# When I first started using this approach, we did the math with paper, pencil and calculator using a handful of manually measured data points. The evolution to computers has opened the door to much more powerful data visualization capabilities.

The analysis bottom line is based on how well the system in question mixes outdoor air (OA) and return air (RA) relative to a theoretical requirement for mixed air (MA), i.e., "perfection." It is important to recognize that while mixing is a key goal for an airside economizer, there are other important, related processes, including minimum outdoor air (MOA) regulation, integration with mechanical cooling, preheat, humidification and dehumidification, and building pressure control.

The technique will flag issues with MOA percentage and preheat and cooling integration but does not directly address building pressure control. Dehumidification and humidification integration are somewhat addressed by the various settings used to define the inflection points in the lines of perfection.

*"Modeling Perfection" *ASHRAE Journal*, October 2021.

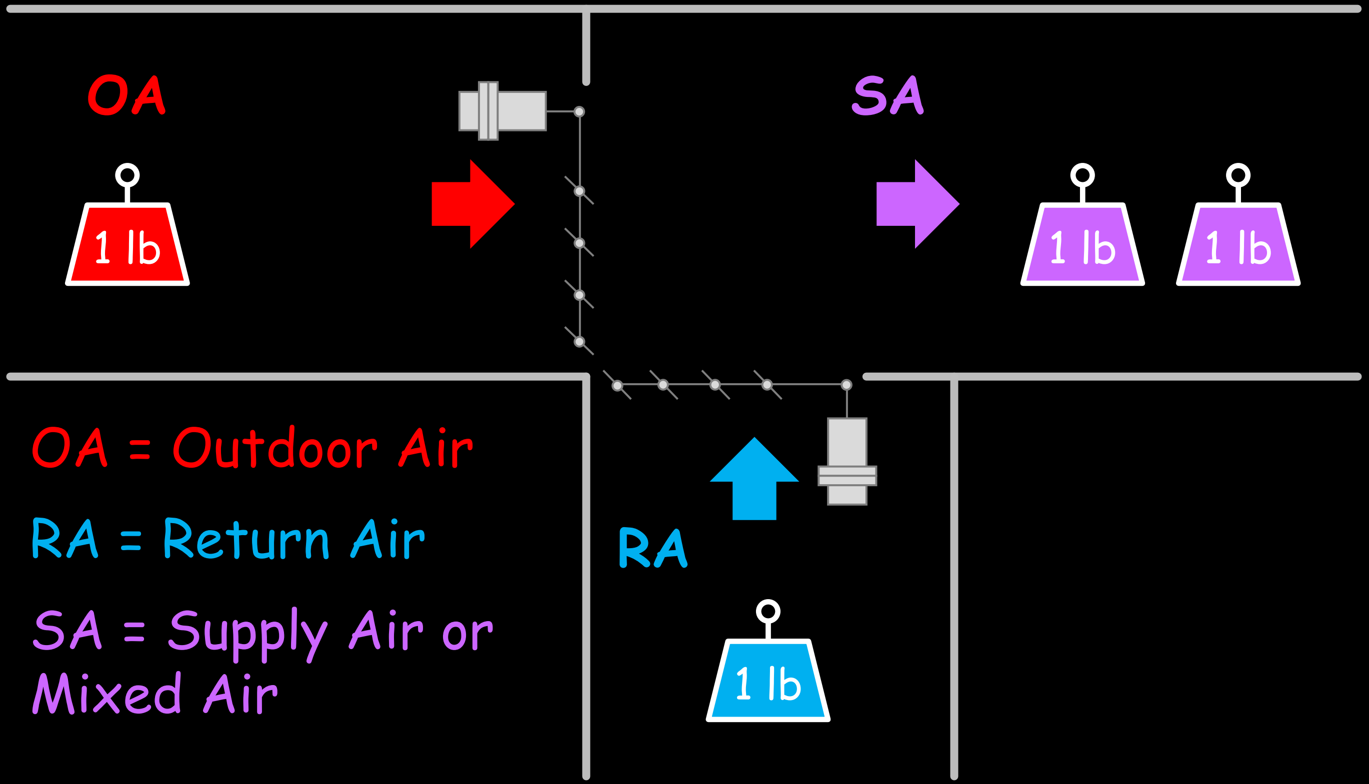
†As a clarifying point, I am going to focus on a perfect airside economizer. But the fundamental principles can be extrapolated to waterside economizers.

§https://tinyurl.com/UTranslate

#For those who would like a starting point, you can download the spreadsheet behind the images in the article at https://tinyurl.com/PerfectEconomizer

David Sellers, P.E., is senior engineer at Facility Dynamics Engineering's office in Portland, Ore.

Conservation of Mass in a Mixed Air Plenum



OA = Outdoor Air

RA = Return Air

SA = Supply Air or Mixed Air

Conservation of Mass in a Mixed Air Plenum

$$\dot{m}_{OutdoorAir} + \dot{m}_{ReturnAir} = \dot{m}_{MixedAir}$$

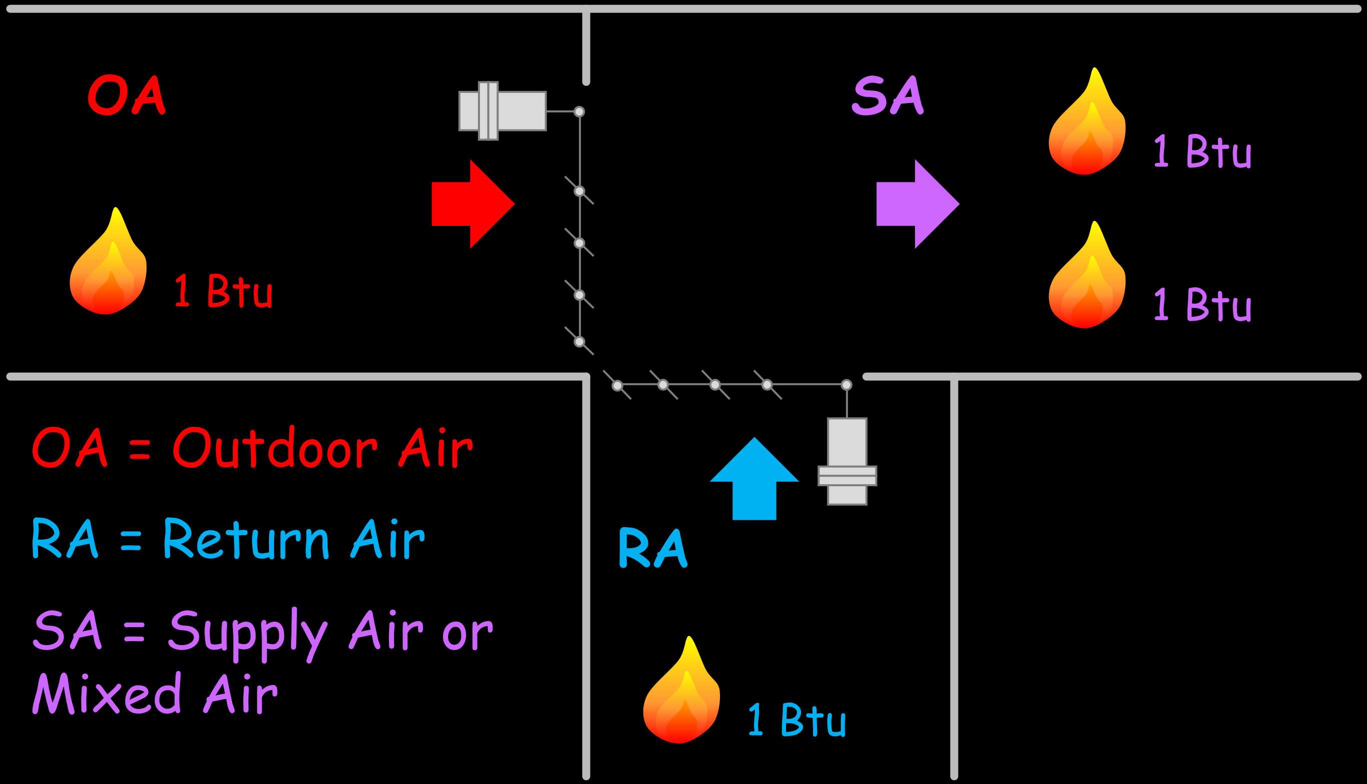
Where:

$\dot{m}_{OutdoorAir}$ = Mass flow rate for outdoor air in consistent units

$\dot{m}_{ReturnAir}$ = Mass flow rate for return air in consistent units

$\dot{m}_{MixedAir}$ = Mass flow rate for mixed air in consistent units

Conservation of Energy in a Mixed Air Plenum



OA = Outdoor Air

RA = Return Air

SA = Supply Air or Mixed Air

This is the first law of thermodynamics

Conservation of Energy in a Mixed Air Plenum

If any system undergoes a process in which energy is added or removed from it (in the form of work or heat), none of the energy added is destroyed with-in the system and none of the energy removed is created with-in the system

Herman Stoever,

Engineering Thermodynamics

This is the first law of thermodynamics

Conservation of Energy in a Mixed Air Plenum

$$Q + u_1 + \frac{p_1 v_1}{J} + \frac{z_1}{J} + \frac{V_1^2}{2gJ} = \frac{W}{J} + u_2 + \frac{p_2 v_2}{J} + \frac{z_2}{J} + \frac{V_2^2}{2gJ}$$

Where:

Q = Heat in Btu/lb

W = Shaft work, ft-lb/lb

u = Internal energy, Btu/lb

pv = Flow work; pressure in lb/ft^2 x specific volume in ft^3/lb, ft-lb/lb

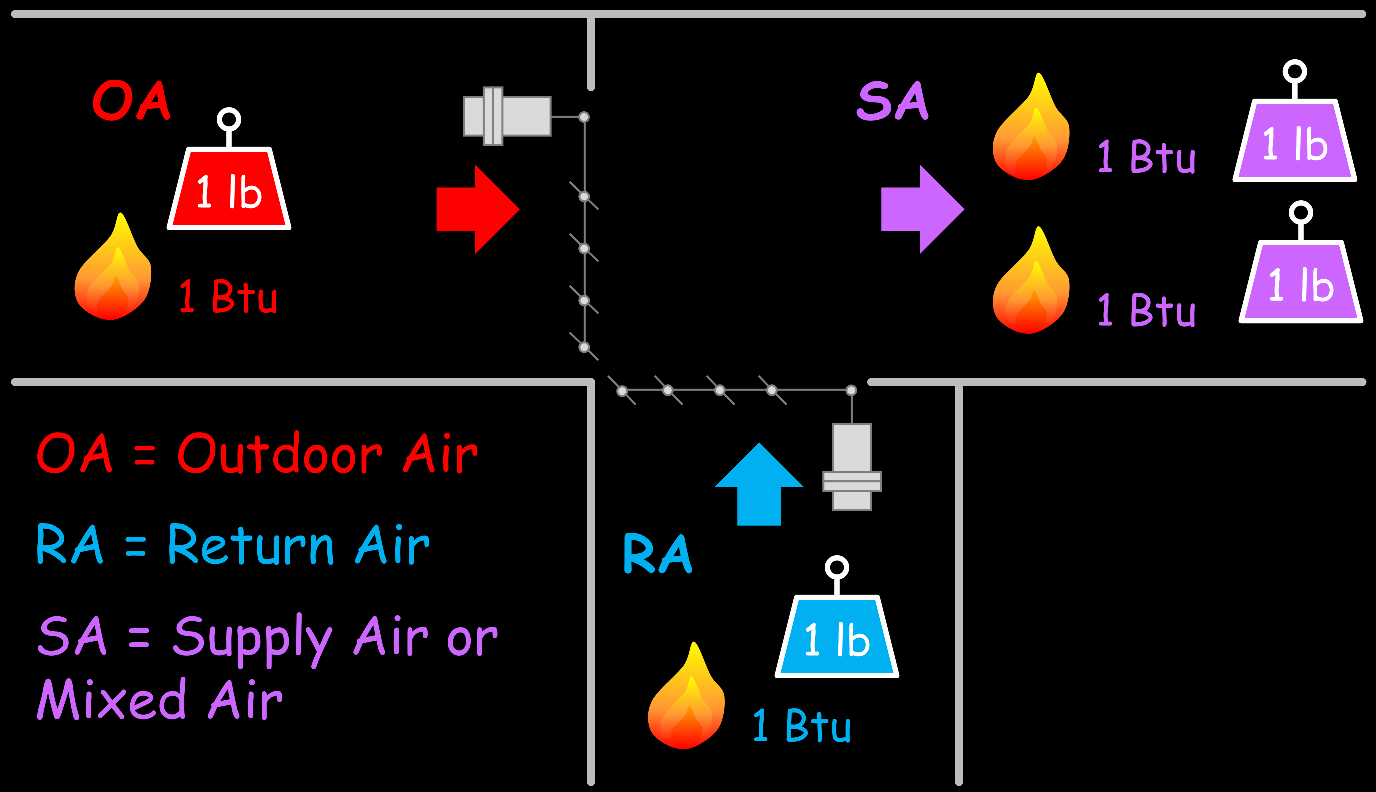
J = Mechanical equivalent of heat; 778 ft-lb/Btu

V = Velocity in feet per second

g = gravitational constant, 32 ft/sec/sec

This is the first law of thermodynamics stated mathematically

Conservation of Mass and Energy in a Mixed Air Plenum



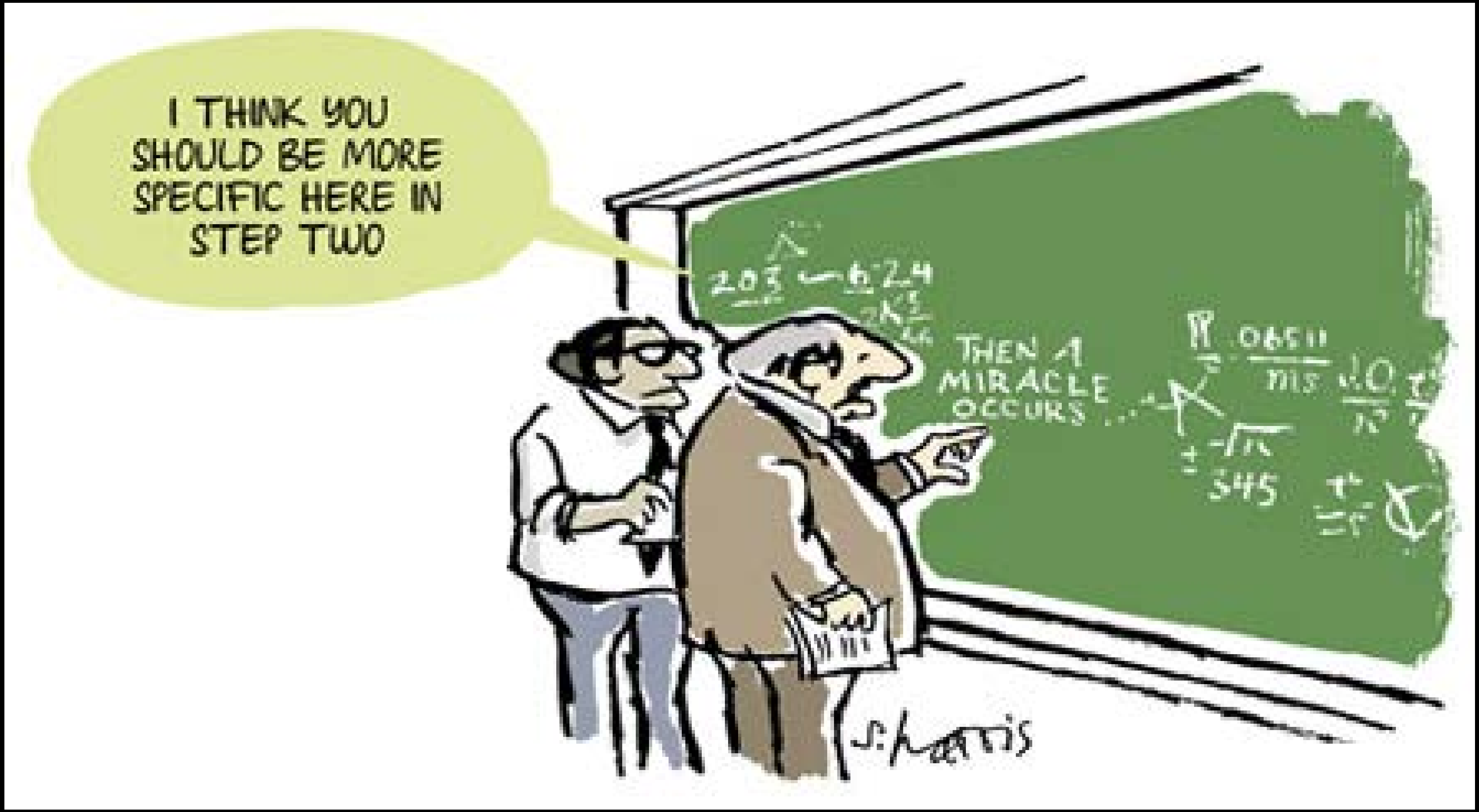
Conservation of Mass and Energy in a Mixed Air Plenum

$$\bar{Q} + \sum_1 \left[\dot{m} \times \left(u_1 + \frac{p_1 v_1}{J} + \frac{z_1}{J} + \frac{V_1^2}{2gJ} \right) \right] = \frac{\bar{W}}{J} + \sum_2 \left[\dot{m} \times \left(u_2 + \frac{p_2 v_2}{J} + \frac{z_2}{J} + \frac{V_2^2}{2gJ} \right) \right]$$

Where the bar over the Q and W terms ($\bar{Q}$ and $\bar{W}$) means that the heat transfer and/or work are being done at some sort of rate, like Btu/hr or ft-lb/hr, and the dot over the m term ($\dot{m}$) means a mass flow rate, like pounds per hour.

The $\sum$ symbol means that the parameters inside the parenthasis are totalled up for all of the fluid streams on each side of the equation.

Fast Forwarding …



Ta-Da

$$\%_{OutdoorAir} = \frac{\left(t_{MixedAir} - t_{ReturnAir}\right)}{\left(t_{OutdoorAir} - t_{ReturnAir}\right)}$$

Assuming perfect mixing

See https://tinyurl.com/MAPlenumPhysics for the in-between steps

A Few Other Useful Relationships

$$t_{OutdoorAir_{Mix32}} = \left[\frac{(32 - t_{ReturnAir})}{\%_{OutdoorAir}} \right] + t_{ReturnAir}$$

Where $t_{OutdoorAir_{Mix32}}$ is the outdoor temperature that will create a freezing condtion in the mixed air plenum.

A Few Other Useful Relationships

$$t_{OutdoorAir} = \left[\frac{\left(t_{MixedAir_{Design}} - t_{ReturnAir} \right)}{\%_{OutdoorAir}} \right] + t_{ReturnAir}$$

Where $t_{MixedAir_{Design}}$ is the design mixed air temperature for the system and $t_{OutdoorAir}$ is the outdoor temperature that will create that condtion.

A Few Other Useful Relationships

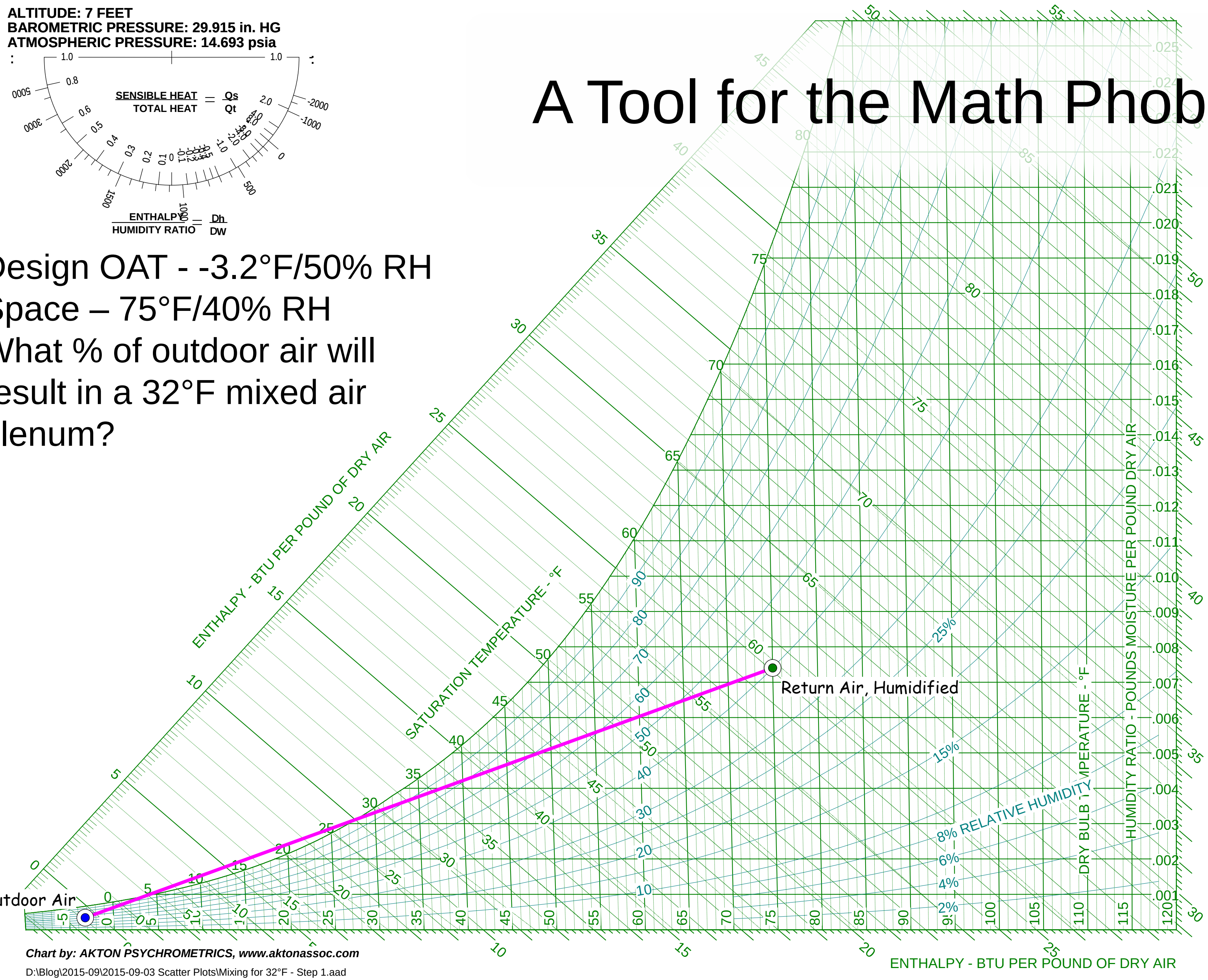
$$t_{MixedAir} = \left[\%_{OutdoorAir} \times \left(t_{OutdoorAir} - t_{ReturnAir}\right)\right] + t_{ReturnAir}$$

Where $t_{MixedAir}$ is the mixed air temperature created by the given outdoor air and return air temperatures and flow percentages ***assuming perfect mixing.***

A tool for doing the math:
https://tinyurl.com/MACalcs

A Tool for the Math Phobic

Design OAT - -3.2°F/50% RH
Space – 75°F/40% RH
What % of outdoor air will result in a 32°F mixed air plenum?



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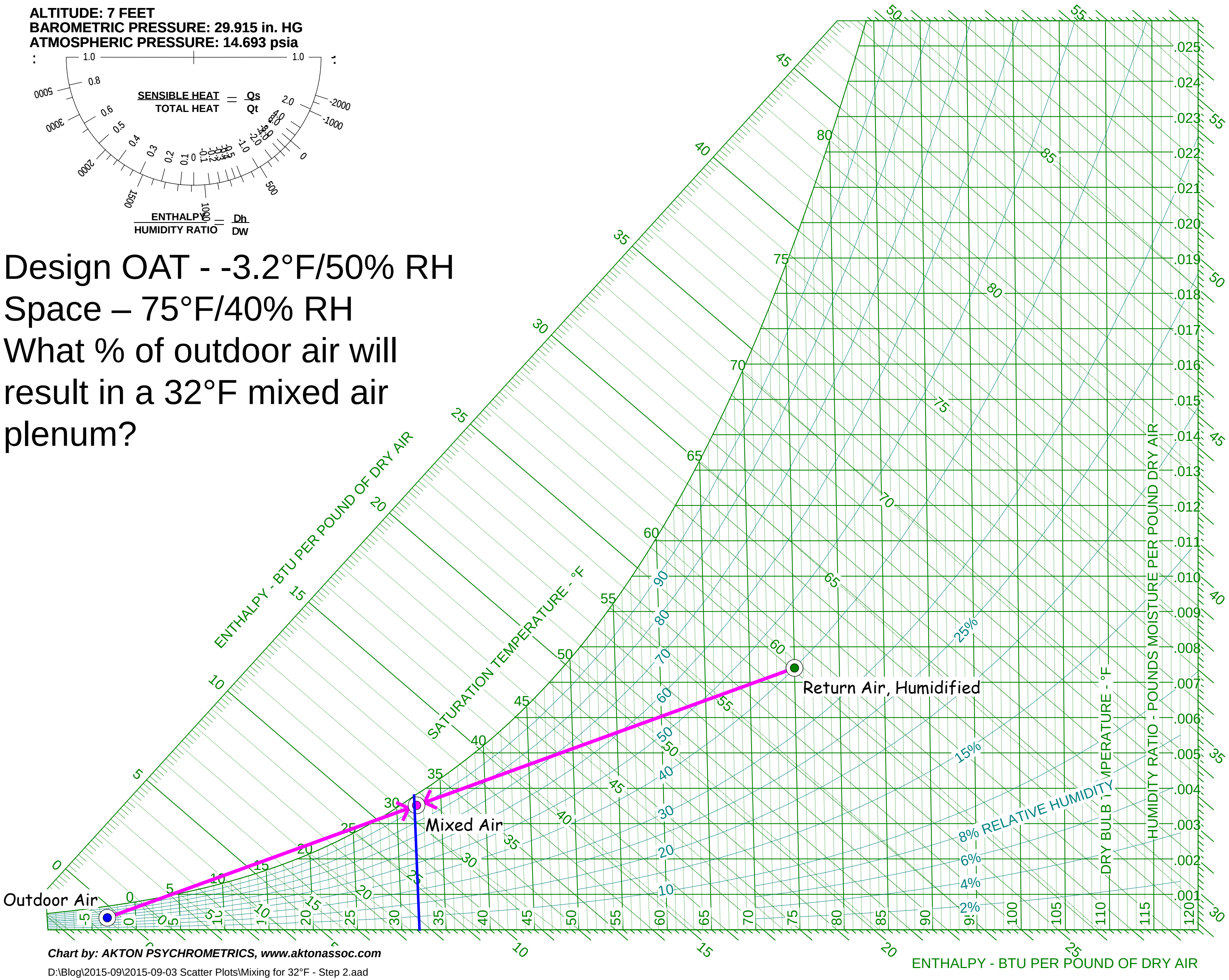

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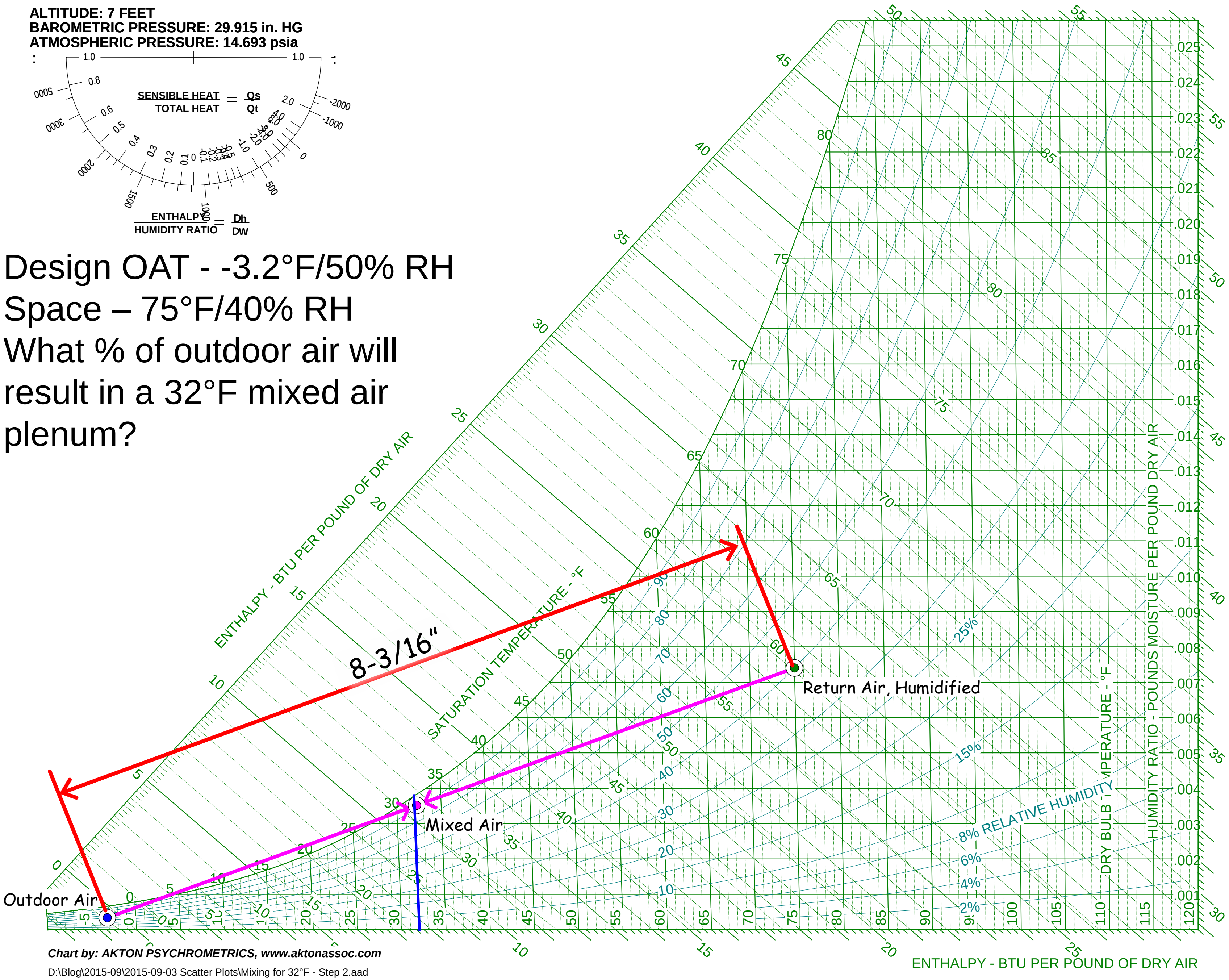

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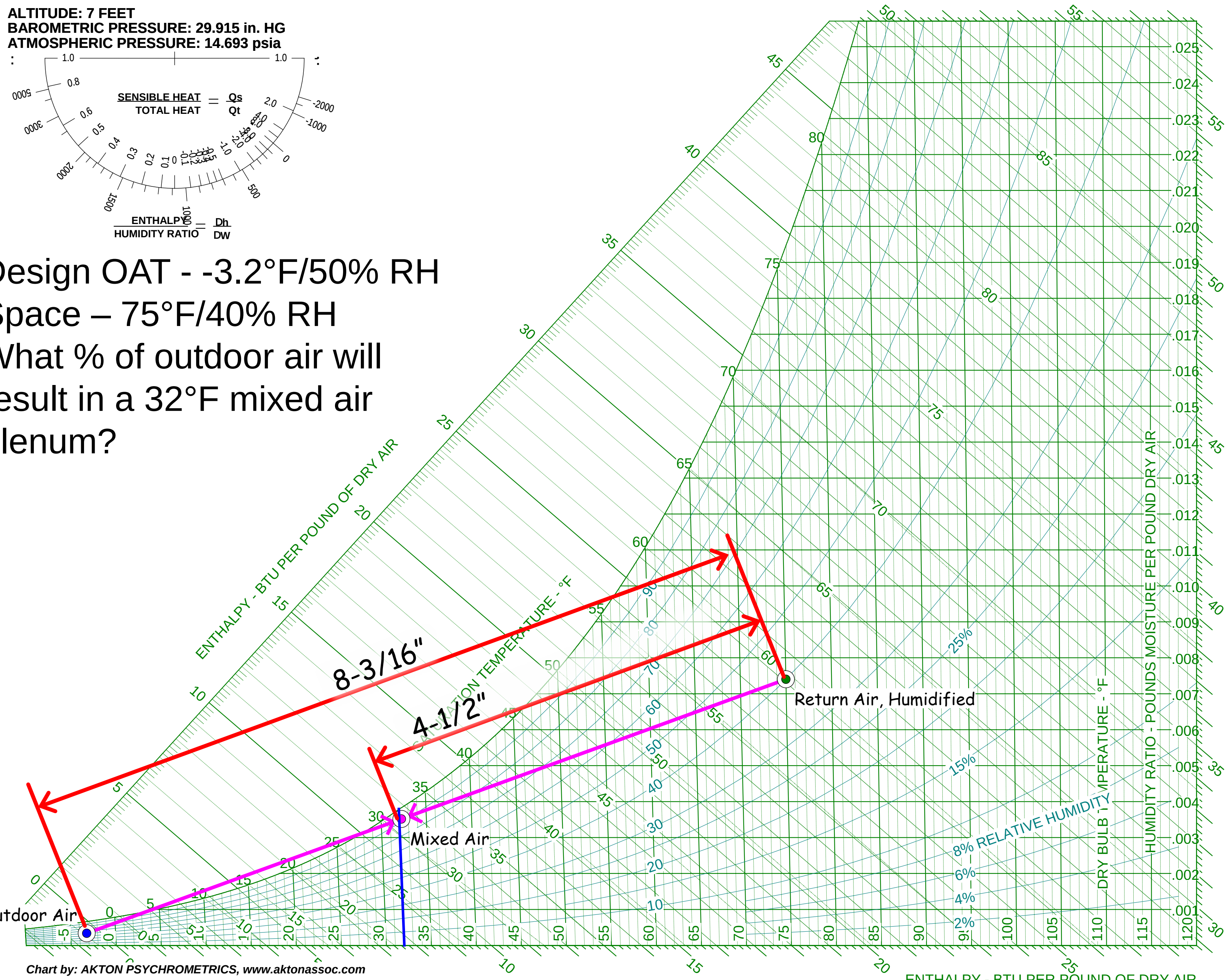
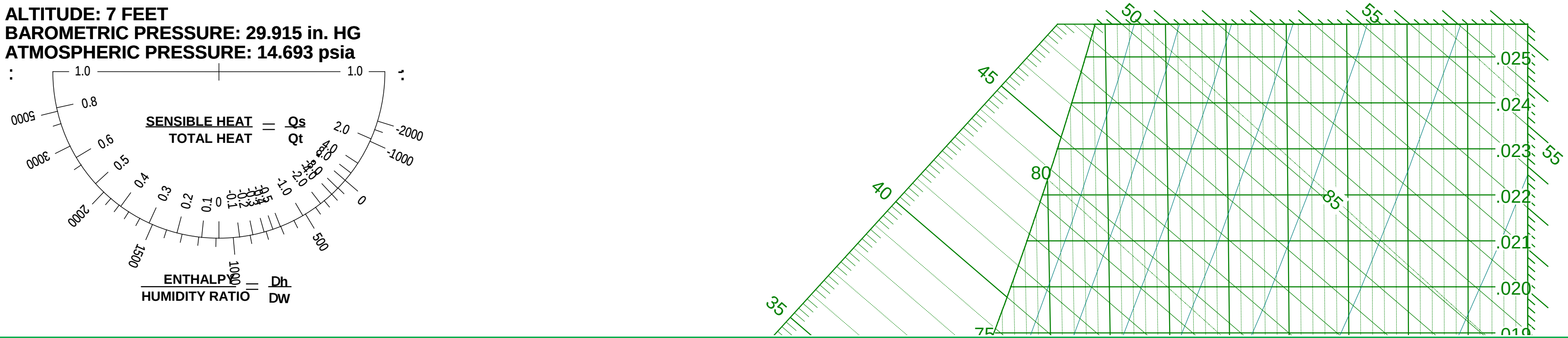


Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com

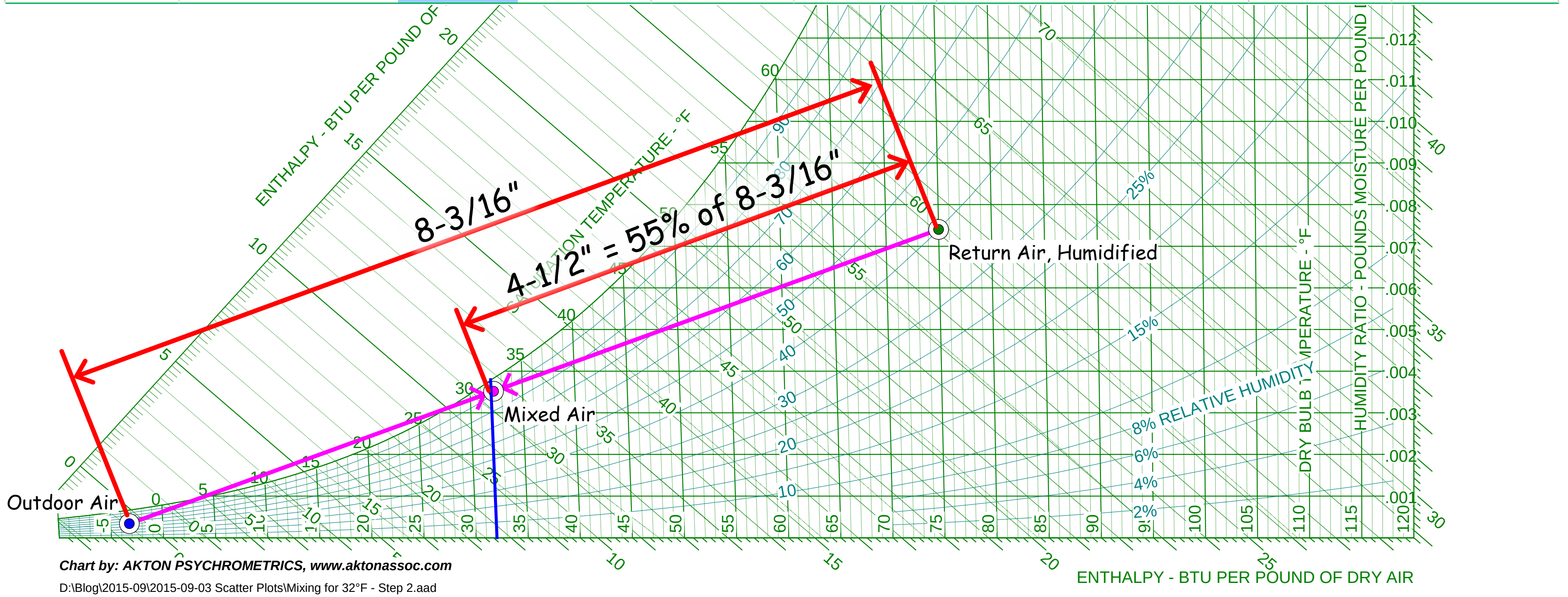
D:\Blog\2015-09\2015-09-03 Scatter Plots\Mixing for 32°F - Step 2.aad



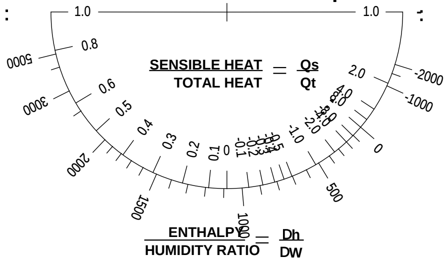
Outdoor percentage based on outdoor air, return air, and supply air temperature

Mixed air temperature (MAT) =	32.0	°F
Return air temperature (RAT) =	75.0	°F
Outdoor air temperature (OAT)=	-3.2	°F
Supply flow (SAF) =	20,000	cfm
Outdoor air flow (OA Flow) =	10,997	cfm
Outdoor air percentage =	55%	
RA Flow =	9,003	cfm

$$\%_{OutdoorAir} = \frac{(t_{MixedAir} - t_{ReturnAir})}{(t_{OutdoorAir} - t_{ReturnAir})}$$



ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia



A video illustrating this technique: https://tinyurl.com/MACalcs at the 36 minute point and the 1 hour and 4 minute point)

Outdoor percentage based on outdoor air, return air, and supply air temperature		
Mixed air temperature (MAT) =	32.0	°F
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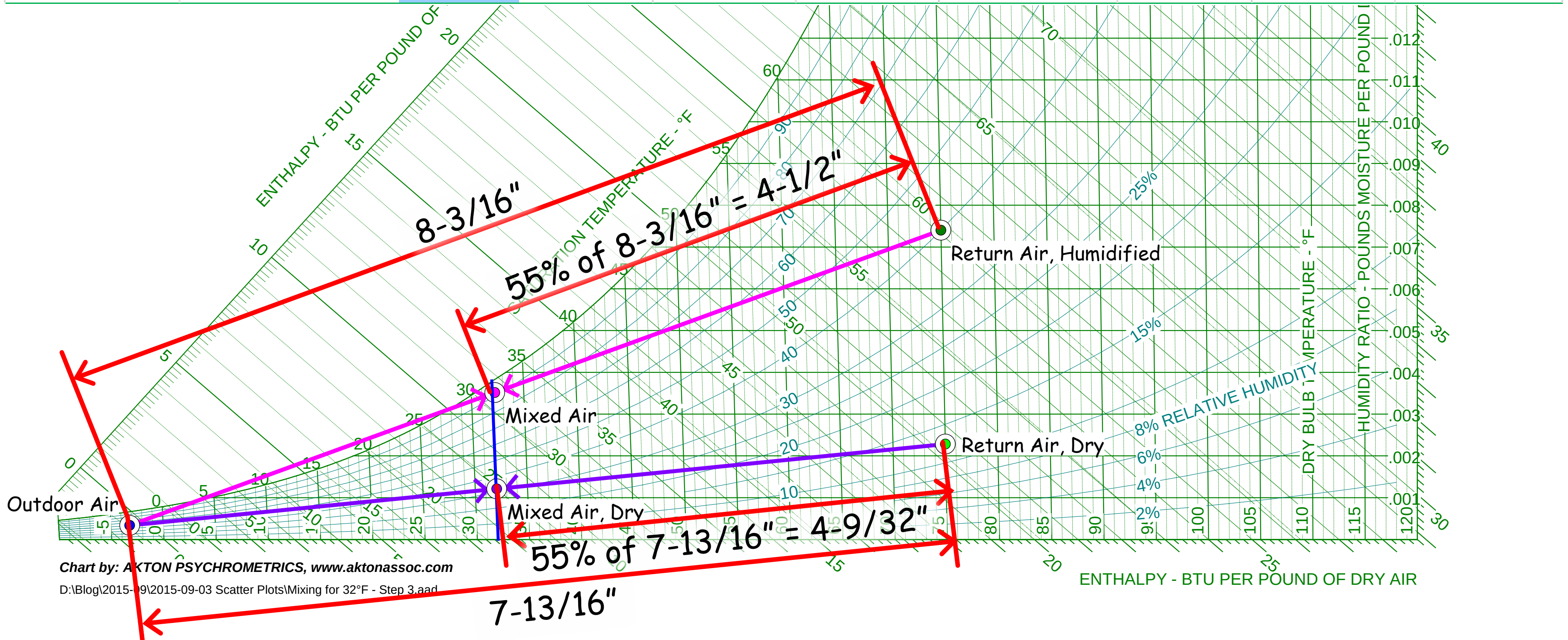

Mixing Effectiveness

Mixing effectiveness defines how well a mixing plenum mixes air on a temperature basis

$$E_{RdT} = 1 - \frac{(t_{Max} - t_{Min})}{(t_{RA} - t_{OA})}$$

Where:

E_{RdT} = Range based mixing effectiveness

t_{Max} = Maximum observed temperature in the measurement plane of the mixed air plenum

t_{Min} = Minimum observed temperature in the measurement plane of the mixed air plenum

t_{OA} = Outside air temperature at the time of assessment

t_{RA} = Return air temperature at the time of assessment

Mixing Effectiveness

It is highly dependent on many, many variables

- Damper sizing
- Damper configuration
  - Parallel or opposed blade
  - Location on the plenum
  - Location relative to each other
- Distance for mixing to happen
- Outdoor air percentage

$$E_{RdT} = 1 - \frac{(t_{Max} - t_{Min})}{(t_{RA} - t_{OA})}$$

Where:

E_{RdT}	=	Range based mixing effectiveness
t_{Max}	=	Maximum observed temperature in the measurement plane of the mixed air plenum
t_{Min}	=	Minimum observed temperature in the measurement plane of the mixed air plenum
t_{OA}	=	Outside air temperature at the time of assessment
t_{RA}	=	Return air temperature at the time of assessment

Mixing Effectiveness

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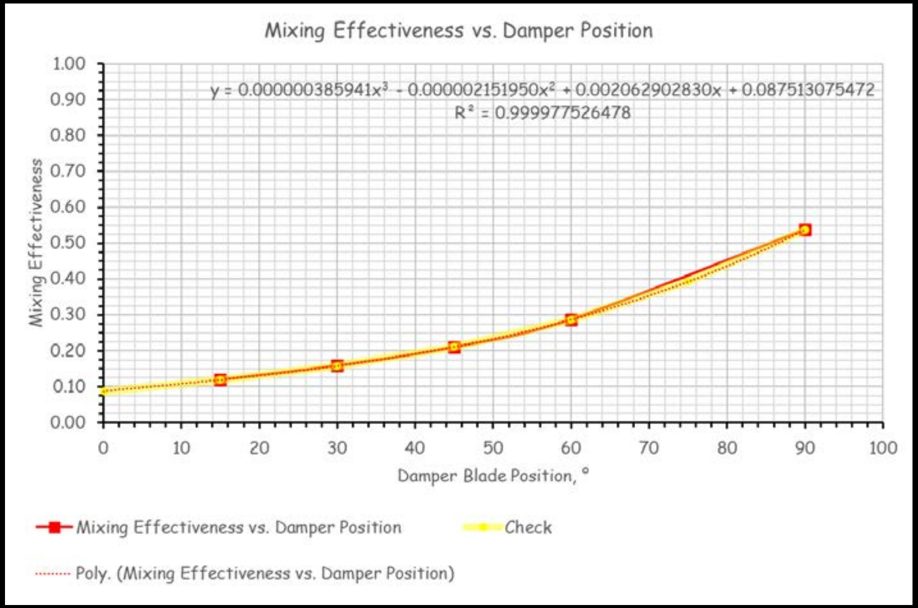

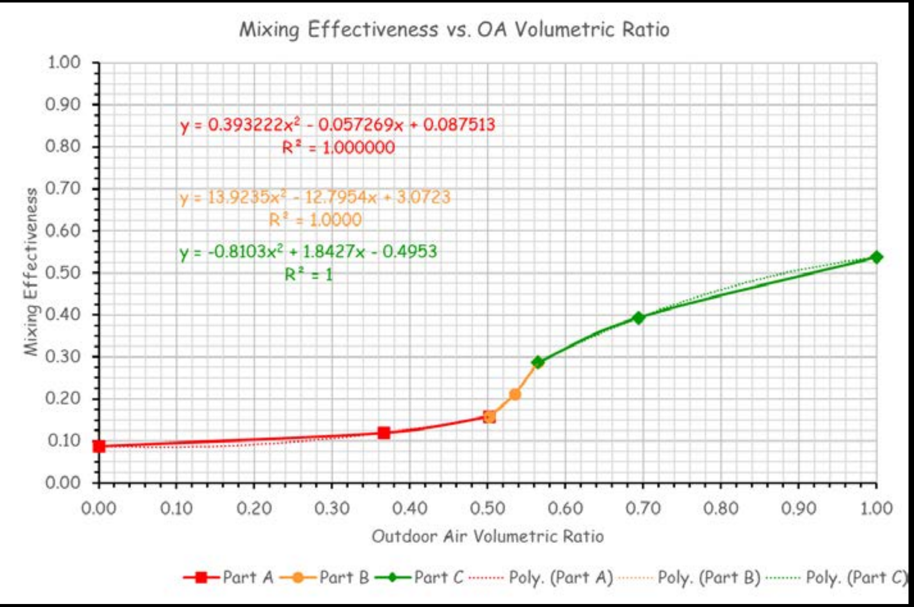

Source: *Mixing Effectiveness of AHU Combination Mixing/Filter Box with and without Filters* by Keith D. Robinson, P.E.

Mixing Effectiveness

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- Damper sizing
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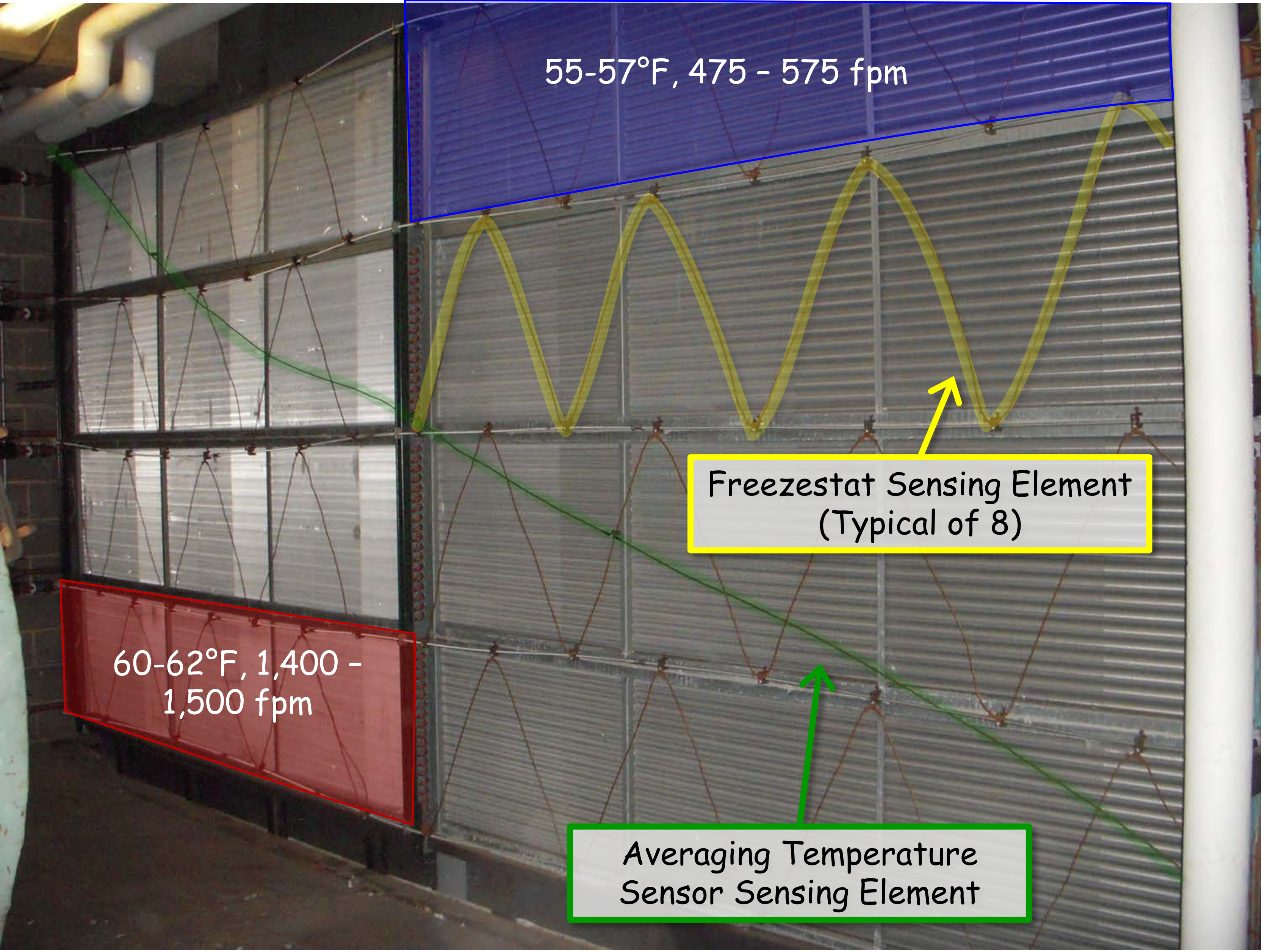
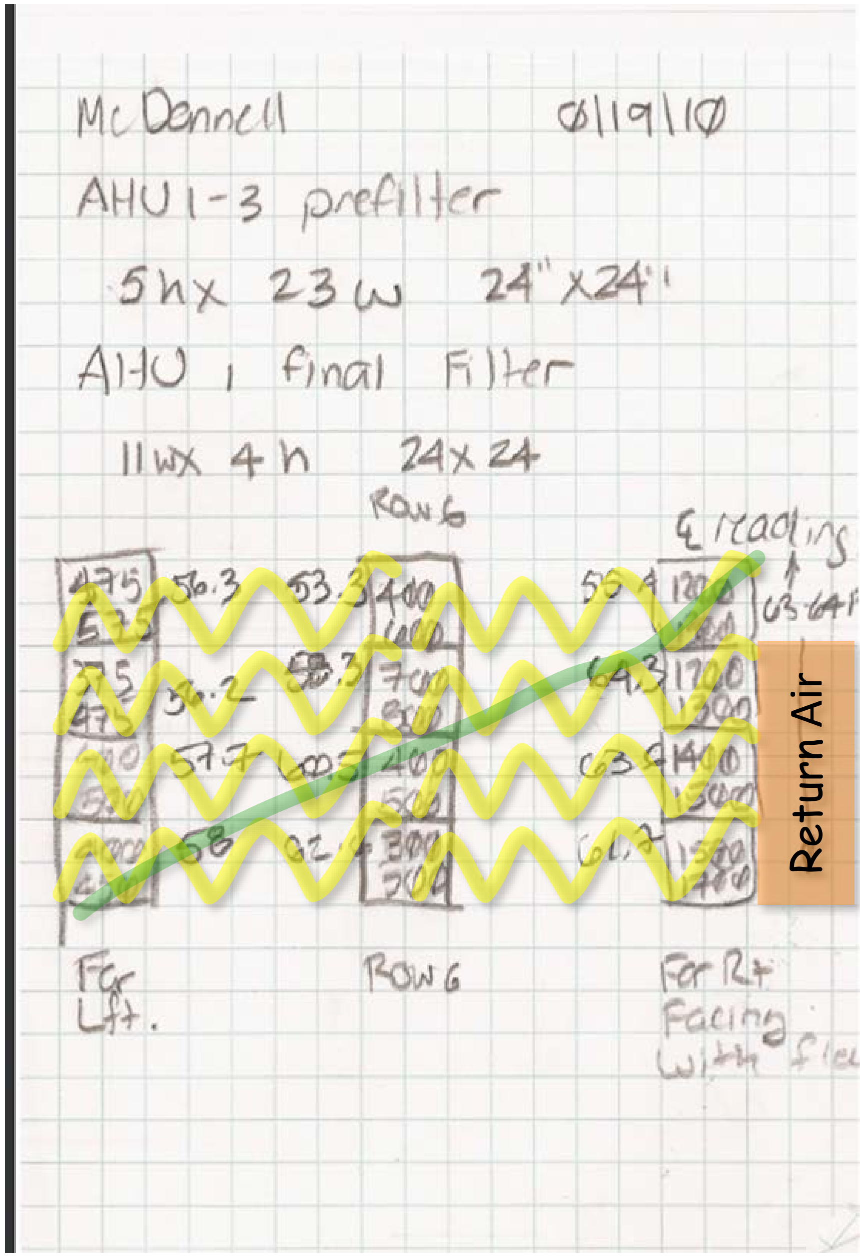
    - Parallel or opposed blade
    - Location on the plenum
    - Location relative to each other
- Distance for mixing to happen
- Outdoor air percentage

Published data

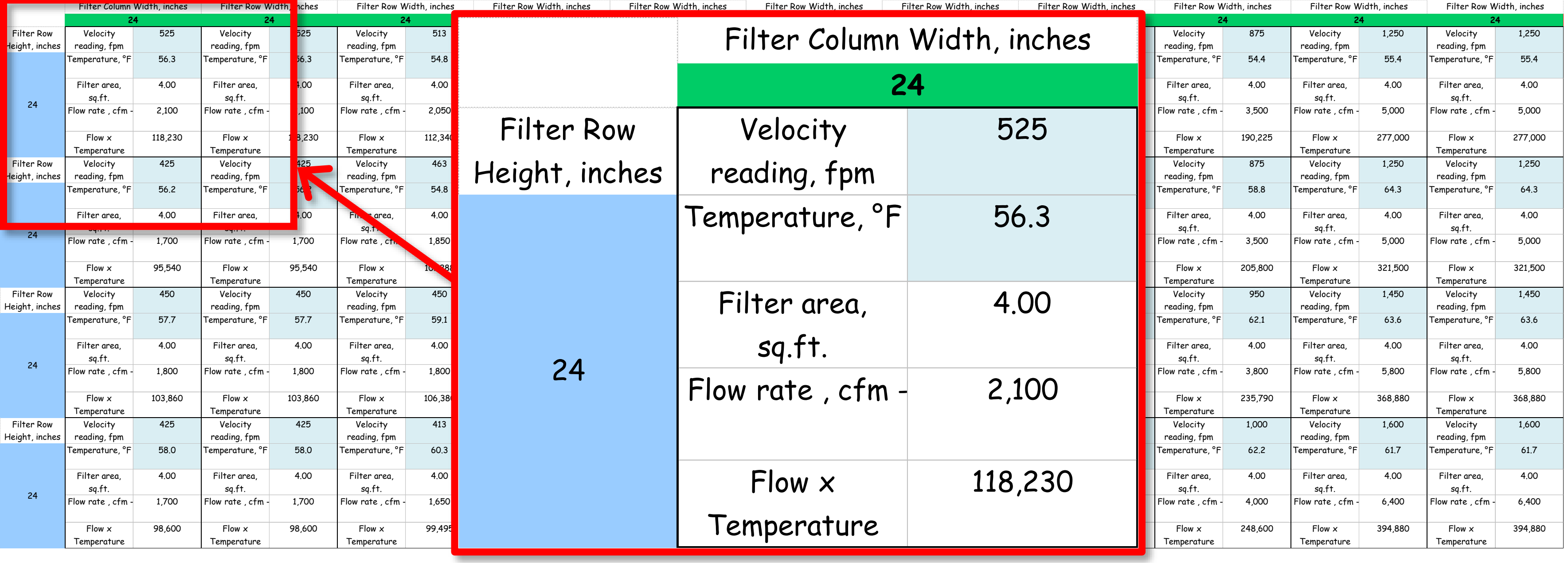
- *Mixing Effectiveness of AHU Combination Mixing/Filter Box with and without Filters* by Keith D. Robinson, P.E.
- *Damper Control Characteristics and Mixing Effectiveness of an Air-Handling Unit Combination Mixing/Filter Box* by Keith D. Robinson, P.E.
- ASHRAE Research Project RP-1045; *Thermal Mixing of Outdoor and Return Airflows in Typical Air-Handling Units*



Leaving Side of Preheat Coil



Temperature and Velocity Measurements at the Filter Bank on the Entering Side of the Coil



	Filter Column Width, inches	
	24	
Filter Row Height, inches	Velocity reading, fpm	525
	Temperature, °F	56.3
24	Filter area, sq.ft.	4.00
	Flow rate , cfm -	2,100
	Flow x Temperature	118,230

Temperature Profile					Coldest / Minimum					Hottest / Maximum	
	24	24	24	24	24	24	24	24	24	24	24
24	56.3	56.3	54.8	54.8	53.3	53.3	53.3	54.4	54.4	55.4	55.4
24	56.2	56.2	54.8	54.8	58.3	53.3	53.3	58.8	58.8	64.3	64.3
24	57.7	57.7	59.1	59.1	60.5	60.5	60.5	62.1	62.1	63.6	63.6
24	58.0	58.0	60.3	60.3	62.6	62.6	62.6	62.2	62.2	61.7	61.7

Velocity Profile					Slowest / Minimum					Fastest / Maximum	
	24	24	24	24	24	24	24	24	24	24	24
24	525	525	513	513	500	500	500	875	875	1250	1250
24	425	425	463	463	750	500	500	875	875	1250	1250
24	450	450	450	450	450	450	450	950	950	1450	1450
24	425	425	413	413	400	400	400	1000	1000	1600	1600

Average outdoor air temperature during the test -	40.0	°F
Average return air teperature during the test -	71.5	°F
Warmest plenum temperature -	64.3	°F
Coldest plenum temperature -	53.3	°F
Mixing effectiveness (see equation to the right) -	0.65	

- The average of the MAT measurements was 57.4F
- The mass-weighted MAT (i.e. the true average) was 58.3°F
- The control system "thought" the temperature was 54.6 (the value read by the averaging sensor; the brown line in the carpet plots.
- A rough assessment of the average temperature seen by the averaging sensor comes out to about 56.5°F
- A rough assessment of the weighted average temperature seen by the averaging sensor comes out to about 56.2°F

Temperature Profile — Coldest … Hottest; Minimum … Maximum

	24	24	24	24	24	24	24	24	24	24	24
24	56.3	56.3	54.8	54.8	53.3	53.3	53.3	54.4	54.4	55.4	55.4
24	56.2	56.2	54.8	54.8	58.3	53.3	53.3	58.8	58.8	64.3	64.3
24	57.7	57.7	59.1	59.1	60.5	60.5	60.5	62.1	62.1	63.6	63.6
24	58.0	58.0	60.3	60.3	62.6	62.6	62.6	62.2	62.2	61.7	61.7

Average outdoor air temperature during the test -	40.0	°F
Average return air teperature during the test -	71.5	°F
Warmest plenum temperature -	64.3	°F
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Velocity Profile — Slowest … Fastest; Minimum … Maximum

	24	24	24	24	24	24	24	24	24	24	24
24	525	525	513	513	500	500	500	875	875	1250	1250
24	425	425	463	463	750	500	500	875	875	1250	1250
24	450	450	450	450	450	450	450	950	950	1450	1450
24	425	425	413	413	400	400	400	1000	1000	1600	1600

Mixed Air Sensor Bottom Lines

1. The sensor needs to see the true mixed air condition
2. This may require multiple sensors that are averaged in software
3. The stratification test can help you understand how many and where to locate them
4. Velocity (mass flow) will skew even the best of temperature readings
5. This is true for diagnostic logging and for process control

Temperature Profile					Coldest						Hottest
					Minimum					Maximum	
	24	24	24	24	24	24	24	24	24	24	24
24	56.3	56.3	54.8	54.8	53.3	53.3	53.3	54.4	54.4	55.4	55.4
24	56.2	56.2	54.8	54.8	58.3	53.3	53.3	58.8	58.8	64.3	64.3
24	57.7	57.7	59.1	59.1	60.5	60.5	60.5	62.1	62.1	63.6	63.6
24	58.0	58.0	60.3	60.3	62.6	62.6	62.6	62.2	62.2	61.7	61.7

Velocity Profile					Slowest						Fastest
					Minimum					Maximum	
	24	24	24	24	24	24	24	24	24	24	24
24	525	525	513	513	500	500	500	875	875	1250	1250
24	425	425	463	463	750	500	500	875	875	1250	1250
24	450	450	450	450	450	450	450	950	950	1450	1450
24	425	425	413	413	400	400	400	1000	1000	1600	1600

Important Point

ASHRAE data and personal experience indicate that the warmest and coldest spot will move around in the plenum as the outdoor air percentage changes

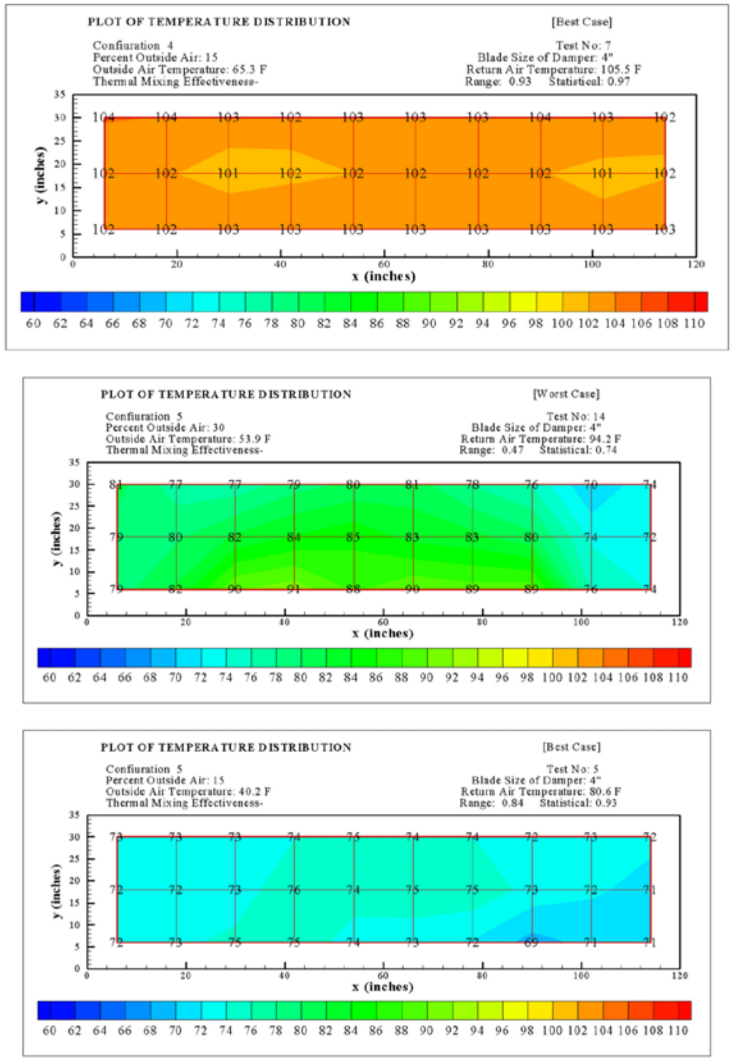
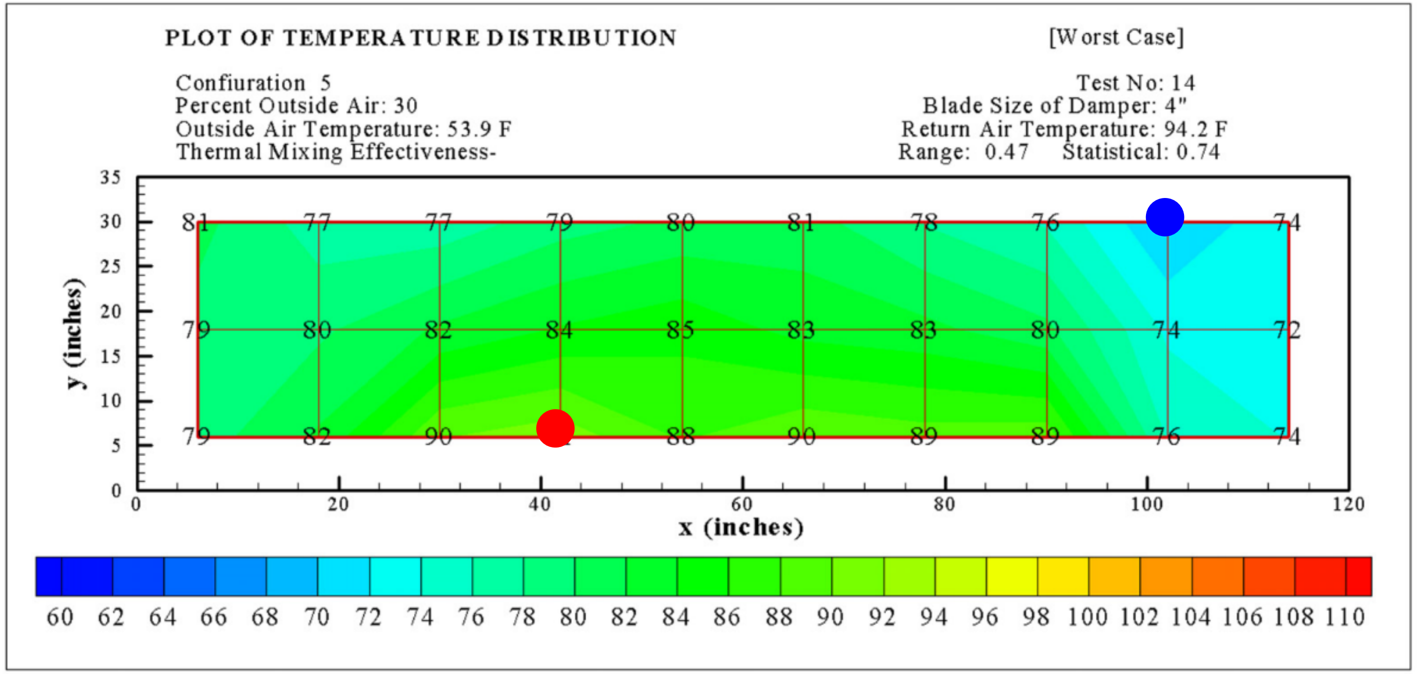
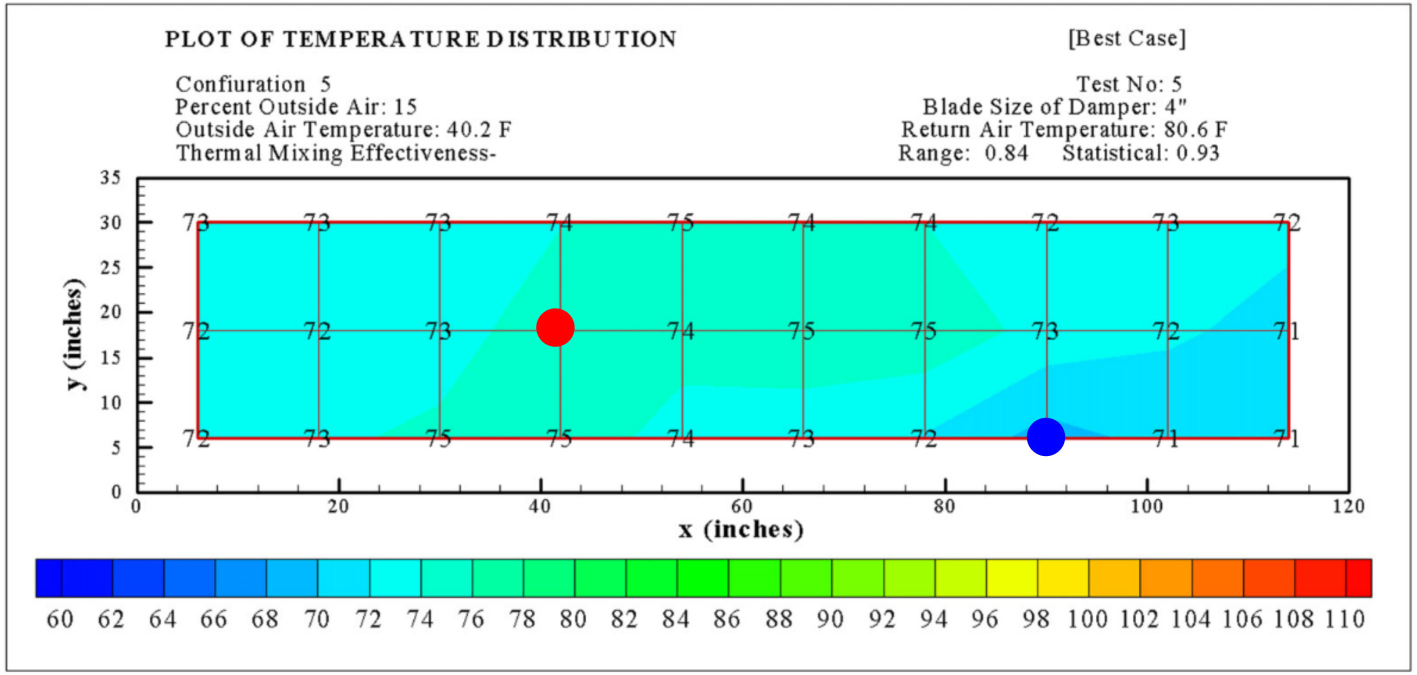


Figure 3b Plots of temperature distribution.

ASHRAE RP-1045

Note that this test maintained a constant 40°F OAT to MAT Δt



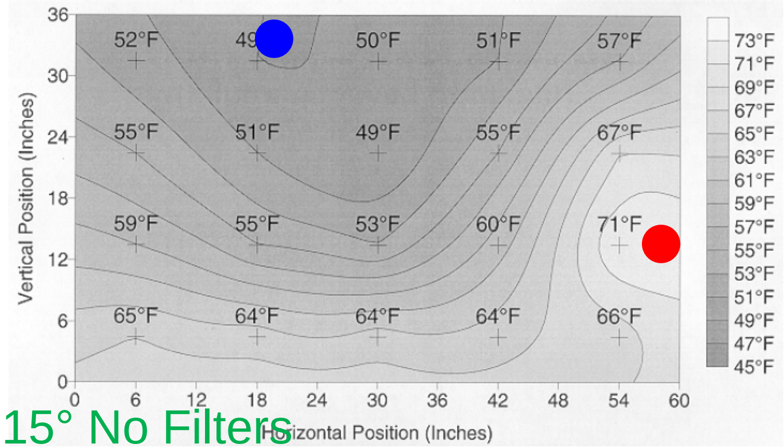


Same configuration with MOA at 30% (top) and 15% (bottom)

- Warm spot
- Cold spot

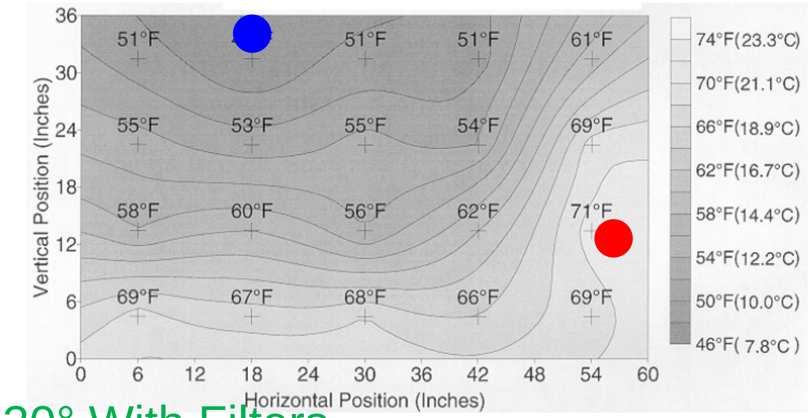
Keith Peterson

Looked at more OA percentages and the impact of filters



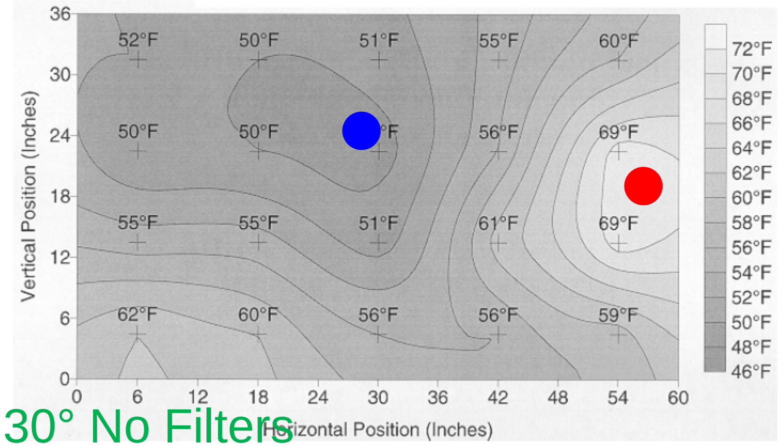
15° No Filters

Figure 5 *Mixing box discharge temperature contour maps without filters in mixing box. OA damper open 15°, T_{OA} = 45°F. RA damper open 75°, T_{OA} = 73°F.*



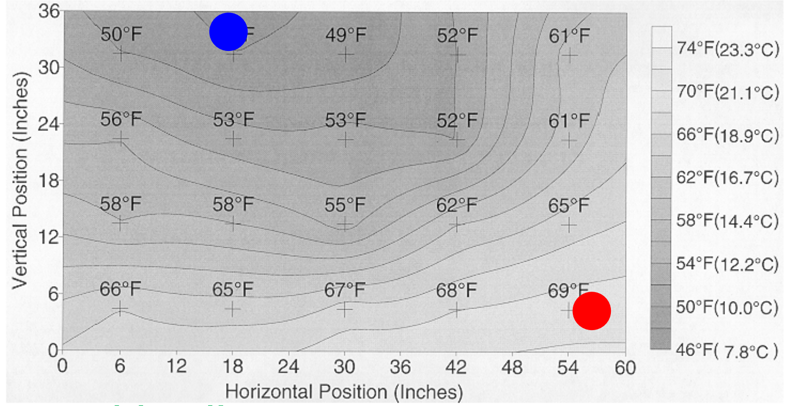
30° With Filters

Figure 6 *Mixing box discharge temperature contour maps with filters installed in mixing box. OA damper open 30°, T_{OA} = 46°F (7.8°C). RA damper open 60°, T_{RA} = 74°F (23.3°C).*



30° No Filters

Figure 7 *Mixing box discharge temperature contour maps without filters installed in mixing box. OA damper open 30°, T_{OA} = 45°F. RA damper open 60°, T_{OA} = 73°F.*

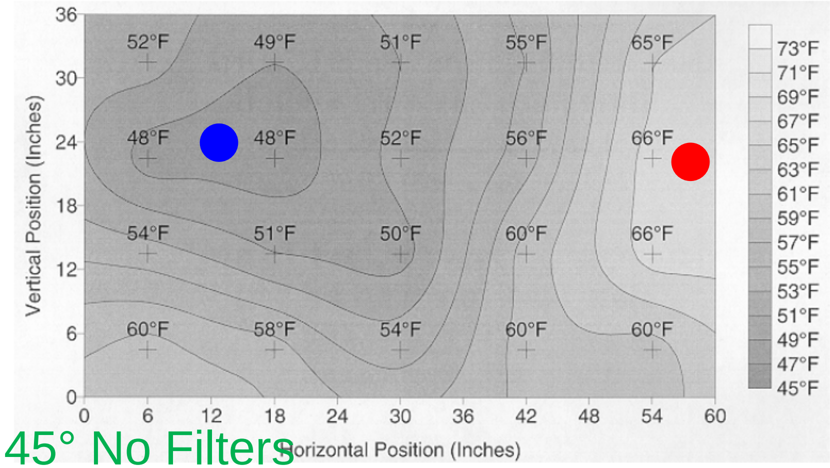


45° With Filters

Figure 8 *Mixing box discharge temperature contour maps with filters installed in mixing box. OA damper open 45°, T_{OA} = 46°F (7.8°C). RA damper open 45°, T_{RA} = 74°F (23.3°C).*

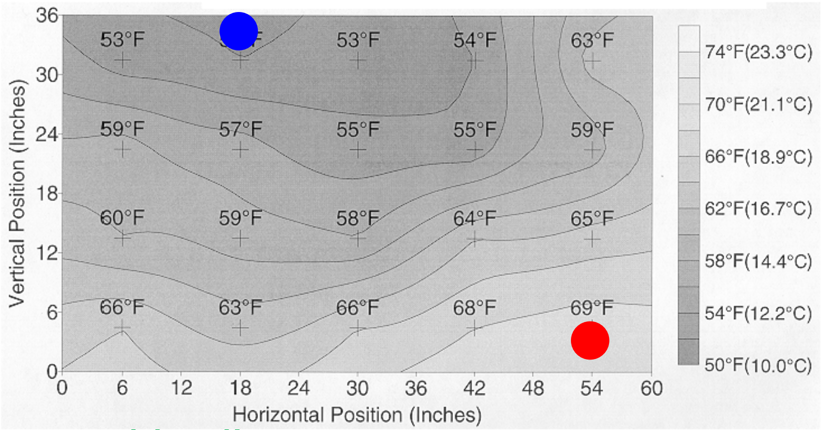
Keith Peterson

Looked at more OA percentages and the impact of filters



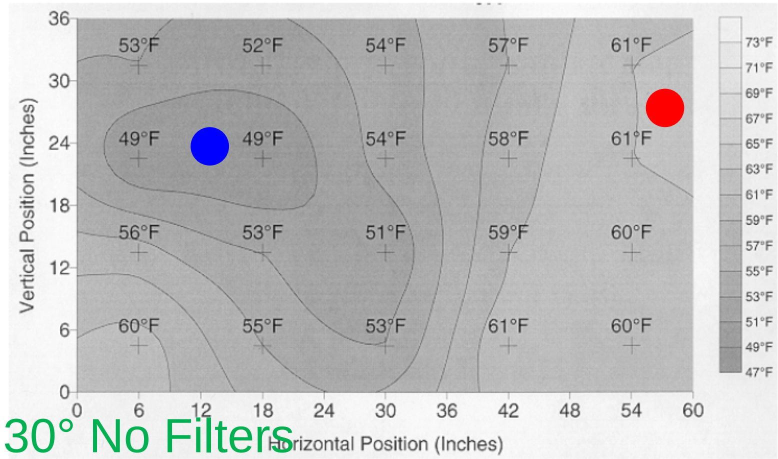
45° No Filters

Figure 9 *Mixing box discharge temperature contour maps without filters installed in mixing box. OA damper open 45°,* T_{OA} *= 45°F. RA damper open 45°,* T_{OA} *= 73°F.*



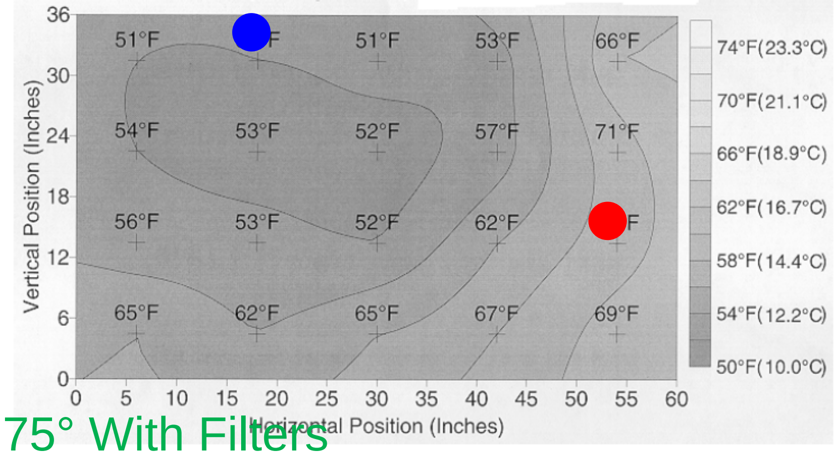
60° With Filters

Figure 10 *Mixing box discharge temperature contour maps with filters installed in mixing box. OA damper open 60°,* T_{OA} *= 50°F (10.0°C). RA damper open 30°,* T_{RA} *= 74°F (23.3°C).*



30° No Filters

Figure 11 *Mixing box discharge temperature contour maps without filters installed in mixing box. OA damper open 60°,* T_{OA} *= 47°F. RA damper open 30°,* T_{OA} *= 73°F.*



75° With Filters

Figure 12 *Mixing box discharge temperature contour maps with filters installed in mixing box. OA damper open 75°,* T_{OA} *= 50°F (10.0°C). RA damper open 15°,* T_{RA} *= 74°F (23.3°C).*

PEC EBCx Class

On 8% (Left), 31% (Center) and 83% OA (Right)

https://tinyurl.com/EconStrat

Temperature Profile

Coldest — Hottest | Minimum | Maximum

8% OA (Left)

	20	20	20	20	20	20	20
20	62.5	63.8	63.1	63.3	64.2	64.5	64.5
20	64.0	62.3	63.5	64.2	64.7	65.3	64.9
20	62.2	62.4	63.8	65.1	64.9	65.0	66.0
20	63.3	65.7	63.3	64.0	65.3	66.8	66.2
20	64.7	64.5	64.2	64.4	65.6	66.3	66.3

31% OA (Center)

	20	20	20	20	20	20	20
20	60.9	60.8	63.5	64.7	64.9	65.4	66.9
20	60.2	61.8	63.3	64.7	64.4	65.9	66.5
20	60.8	61.5	64.0	65.1	69.9	66.3	66.5
20	60.0	60.9	64.0	64.9	66.2	66.7	66.7
20	60.0	61.7	64.4	65.4	66.7	67.1	67.1

83% OA (Right)

	20	20	20	20	20	20	20
20	57.5	57.3	57.0	55.4	53.9	52.7	52.5
20	57.5	57.9	57.0	55.9	53.9	52.7	52.1
20	58.4	58.1	57.0	57.9	54.1	52.5	52.5
20	58.8	57.9	58.1	55.4	53.7	52.5	51.8
20	59.3	57.3	55.7	54.3	52.7	52.3	52.8

Velocity Profile

Slowest — Fastest | Minimum | Maximum

8% OA (Left)

	20	20	20	20	20	20	20
20	526	506	604	564	623	604	447
20	604	681	604	663	663	506	526
20	721	447	272	252	447	409	429
20	584	487	546	526	447	623	526
20	429	389	405	405	546	350	447

31% OA (Center)

	20	20	20	20	20	20	20
20	584	409	584	584	623	526	506
20	623	567	604	564	584	650	526
20	604	584	506	389	506	584	701
20	564	564	564	564	370	584	564
20	429	350	467	487	584	564	487

83% OA (Right)

	20	20	20	20	20	20	20
20	331	350	272	643	779	643	632
20	350	292	370	741	945	799	653
20	800	604	429	760	858	643	701
20	681	487	604	663	741	663	604
20	467	487	623	389	447	487	623

Presidio of Monterey EBCx

Visit https://tinyurl.com/EconStrat for details

Enter start date and time

4/20/15 4:00

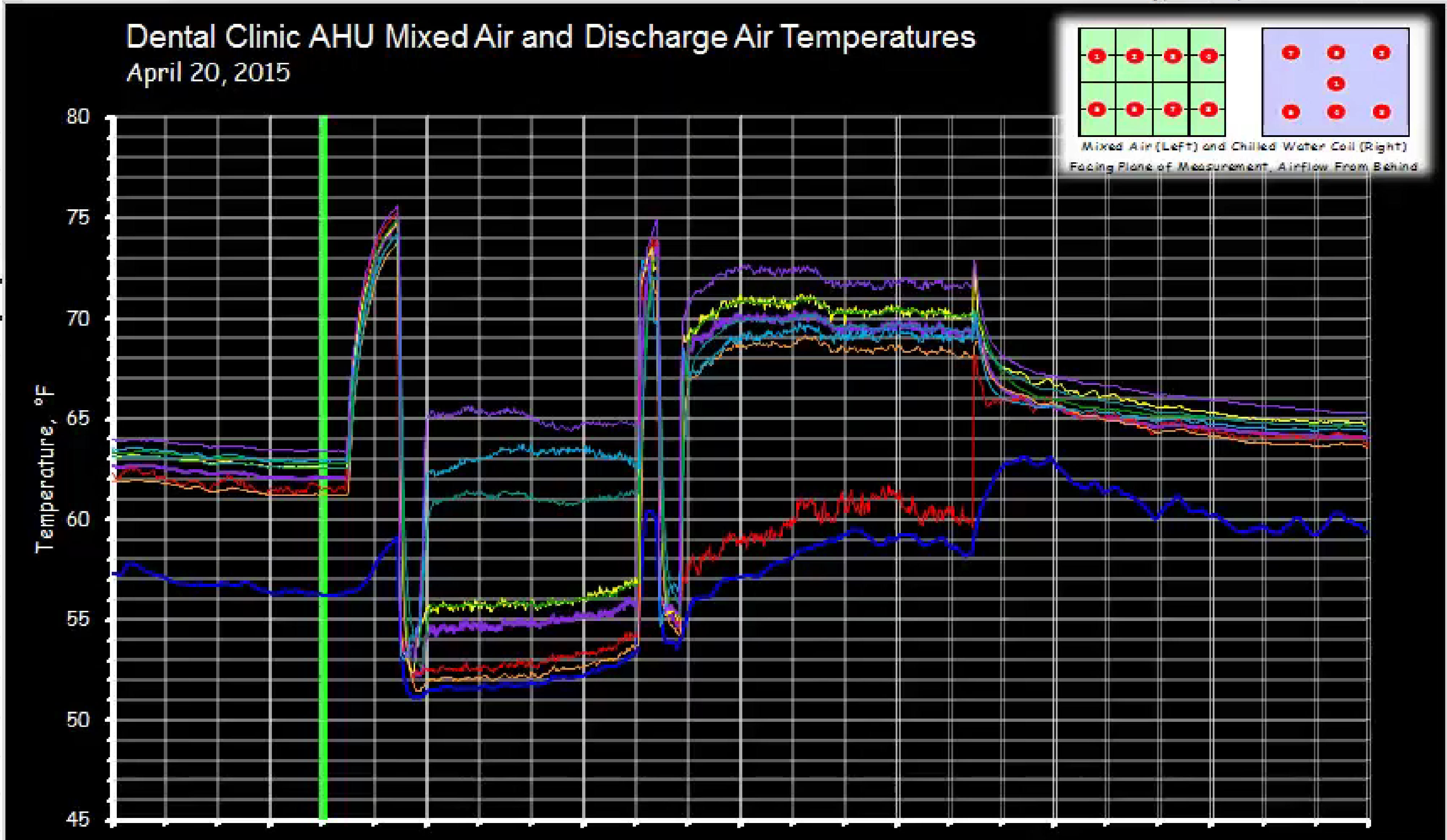
added minutes: 0

carpet plot showing time:
4/20/15 4:00

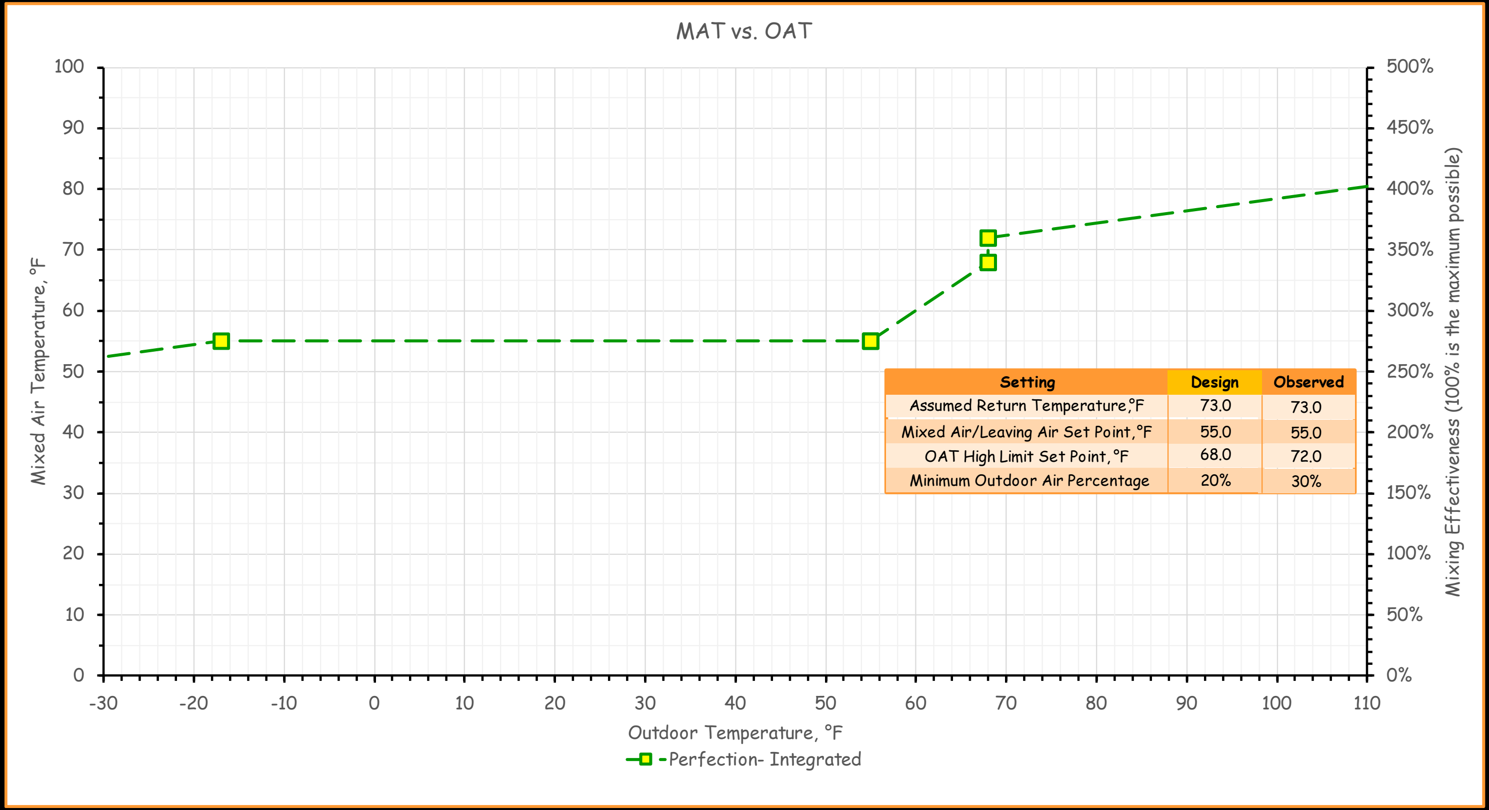
Scroll bar to change time

62.1	61.5	61.2	62.6
62.1	61.5	61.2	62.6
62.9	62.9	62.6	63.4
62.9	62.9	62.6	63.4

min 61.2
max 63.4



Modeling Shapes in the Clouds Around the Lines of Perfection for an Economizer Cycle



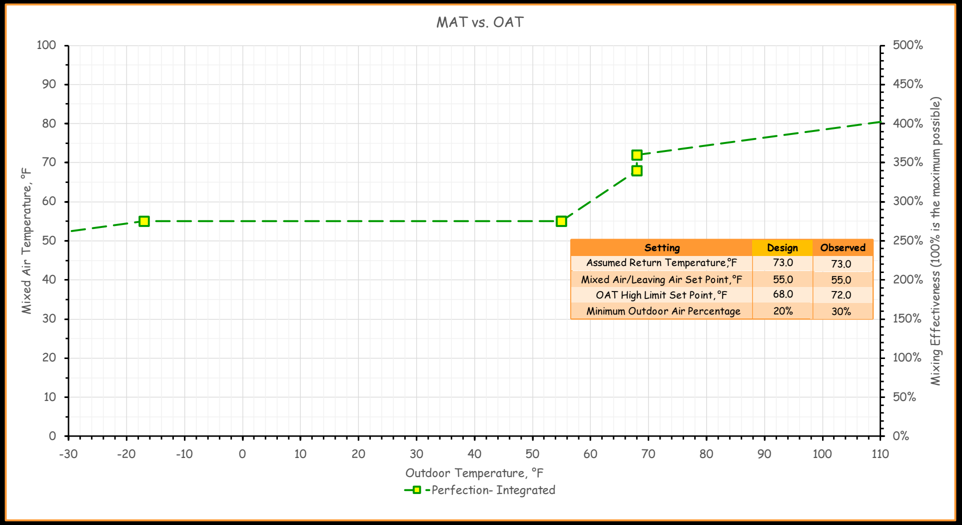
A Few Things to Know about the Clouds that Follow

1. They are not real data, rather, they are created with a spreadsheet tool
2. The tool uses an hourly weather data file, engineering calculations, and logic to simulate the MAT vs. OAT relationship that you would see for various economizer operating conditions
3. The tool uses hourly data to allow the picture of an entire year to be painted; a Minneapolis-St. Paul, Minnesota TMY3 file was used for these slides
4. Meaningful logger data for an analysis of this type likely needs to sampled a 15 minutes for the OAT and 1-5 minutes for the MAT; faster is better for the MAT.
5. The patterns match my experience and observations over the course of my career but are a bit more perfect than real data would be

A Few Things to Know about the Spreadsheet Tool Behind the Clouds

The Tool as a Training Aid

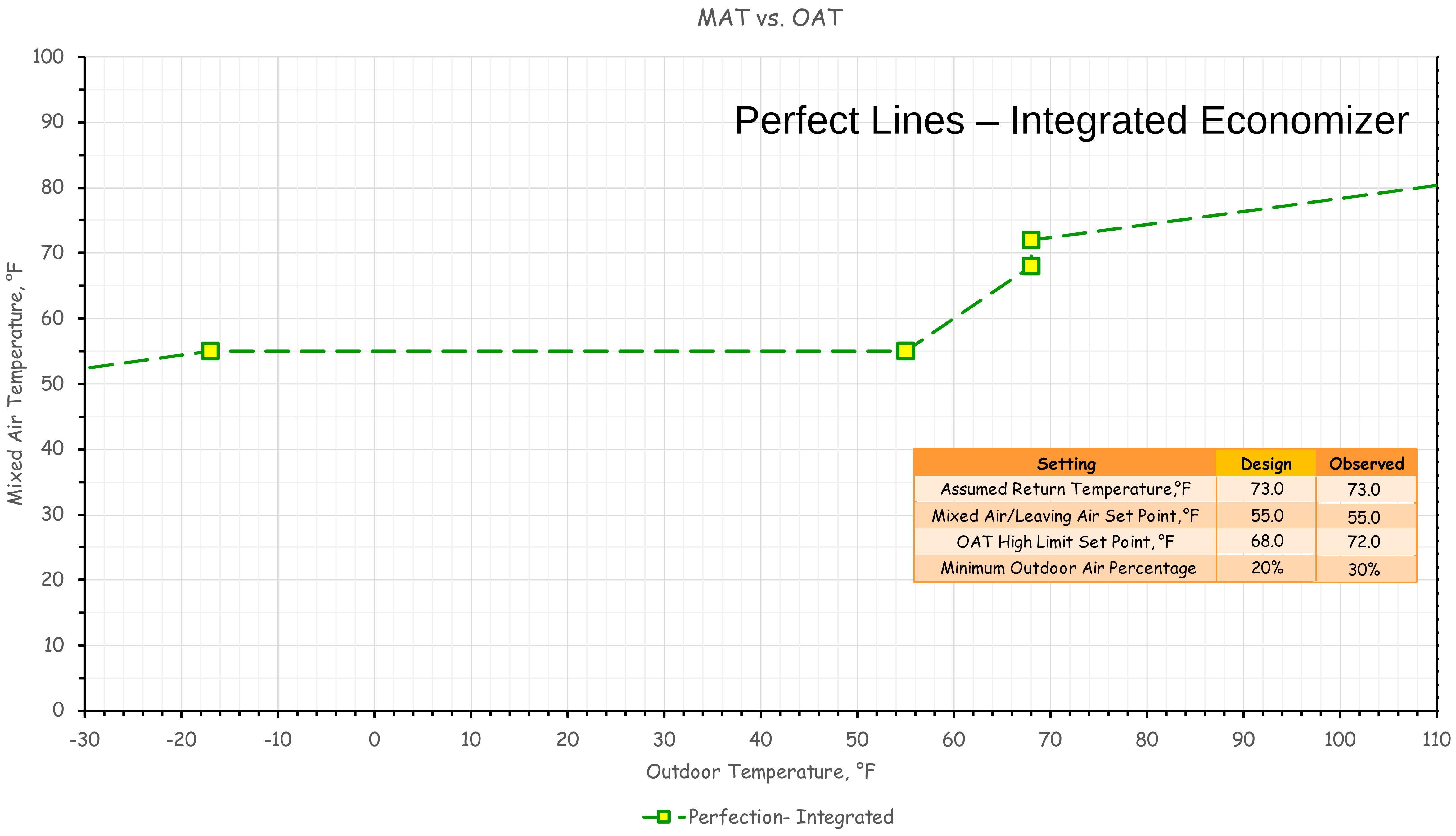
1. Models integrated and no-integrated economizers
2. Models normal operation and common faults and allows them to be contrasted
3. Models the impact of improved mixing effectiveness



The Tool as a Diagnostic Aid

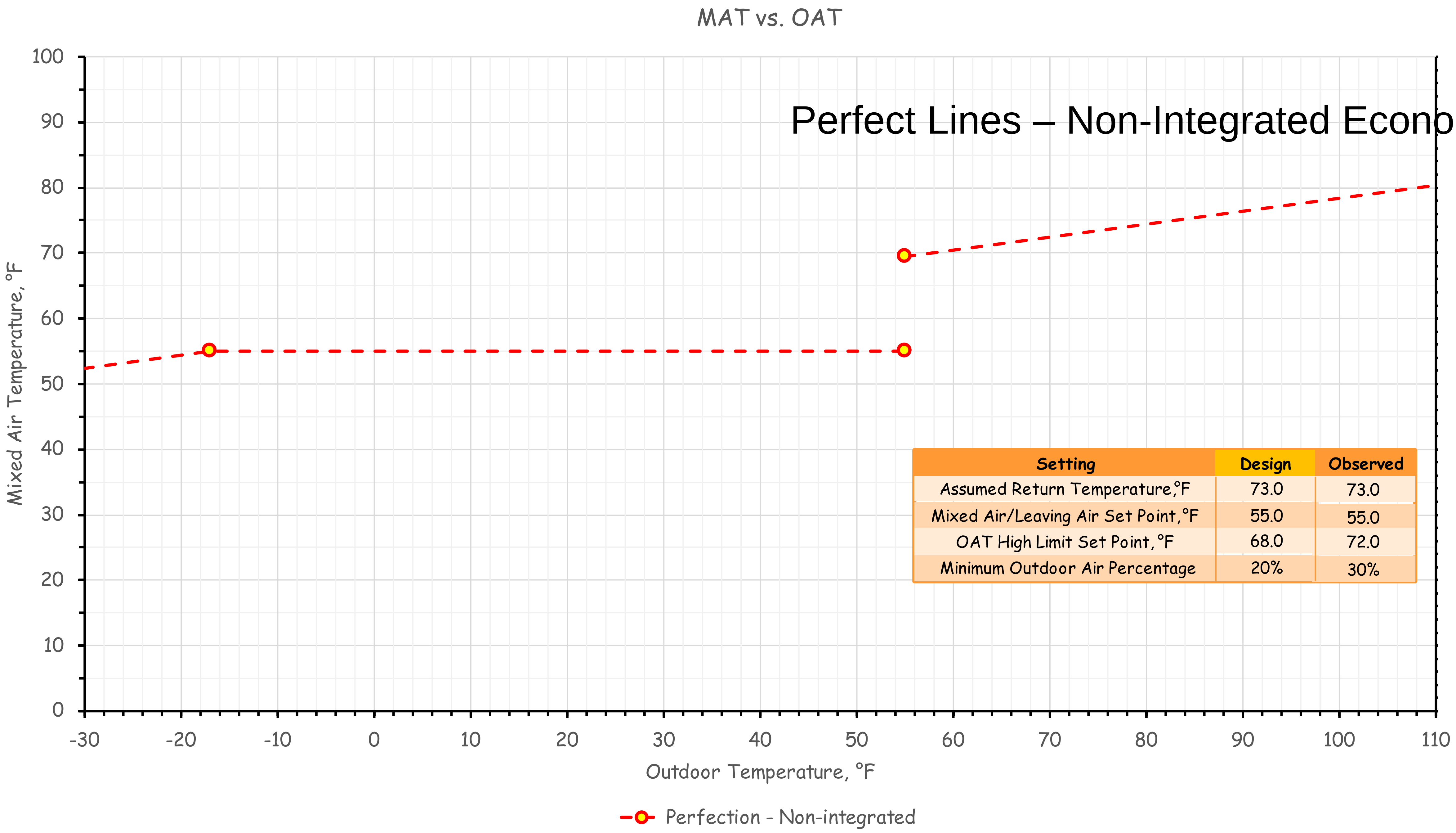
1. Real data can be added to the charts to allow it to be contrasted with the various operating patterns
2. The potential for coil freeze-ups can be assessed for a functional economizer in a given climate with a field-based input for the mixing effectiveness
3. The number of hours were a given disfunction would cause problems can be assessed
4. Rough order of magnitude savings projections can be developed using the data for the contrast between actual and ideal operation for a given system

Perfect Lines – Integrated Economizer

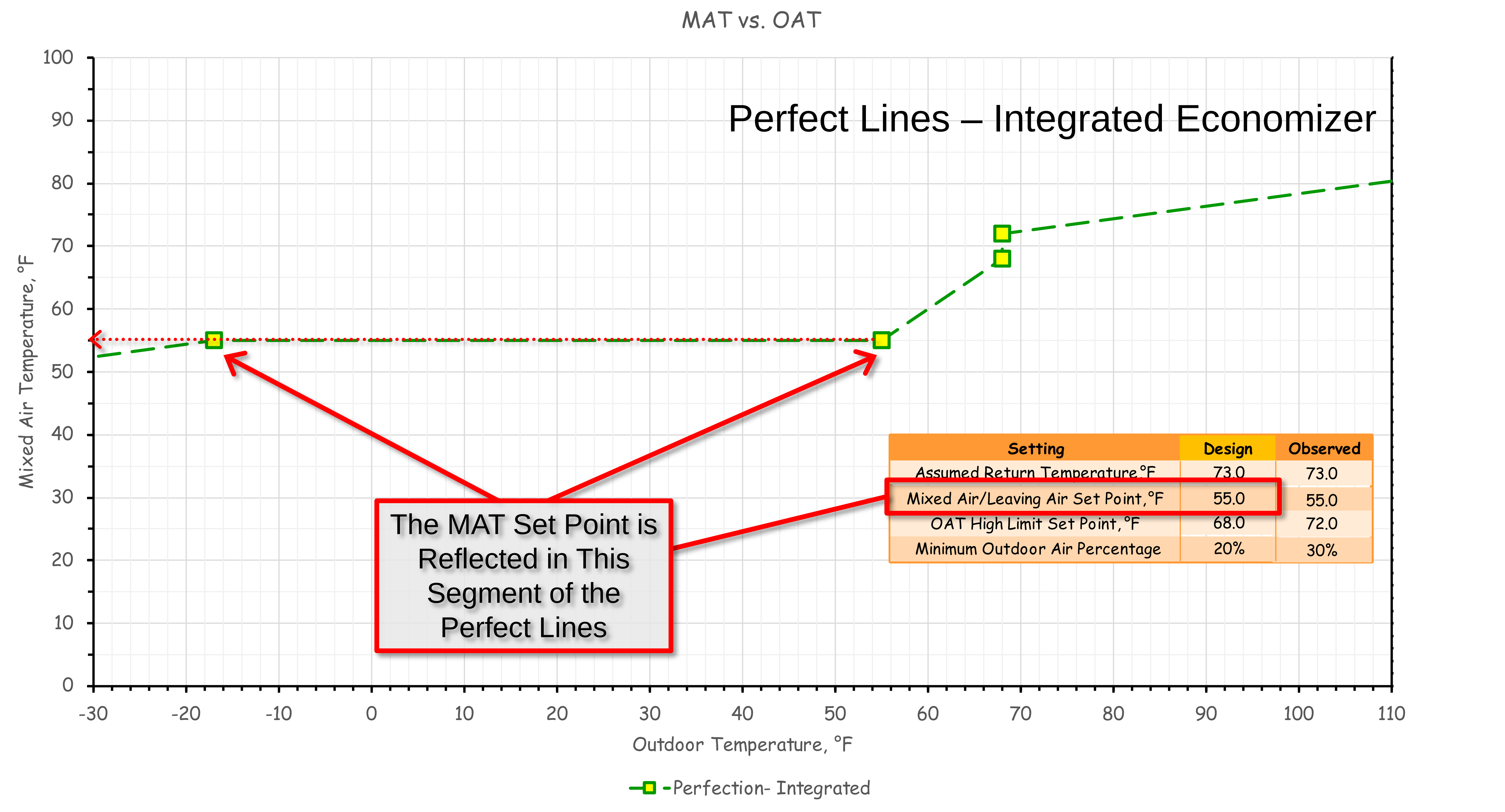


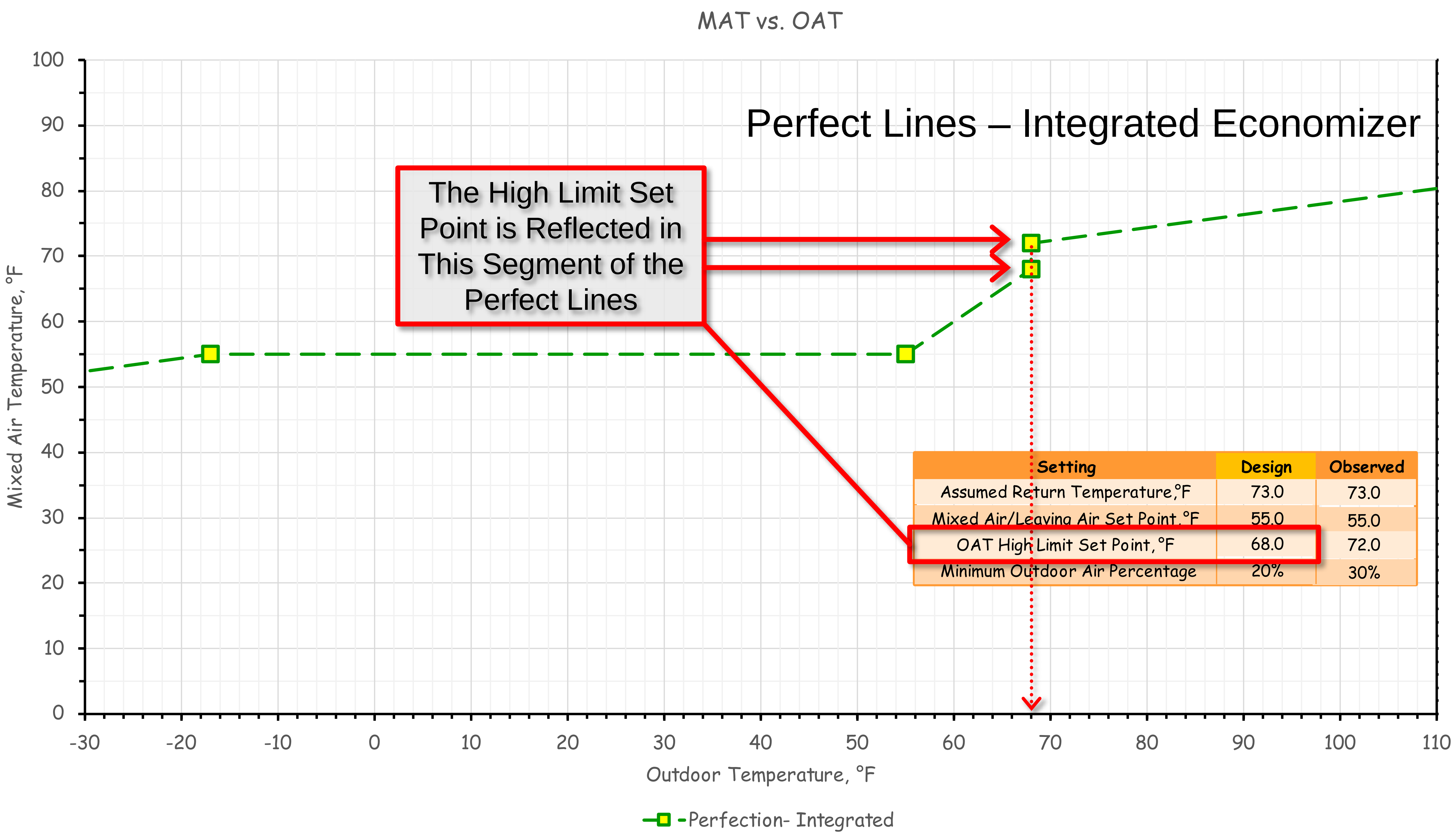
Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point,°F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%

Perfect Lines – Non-Integrated Economizer

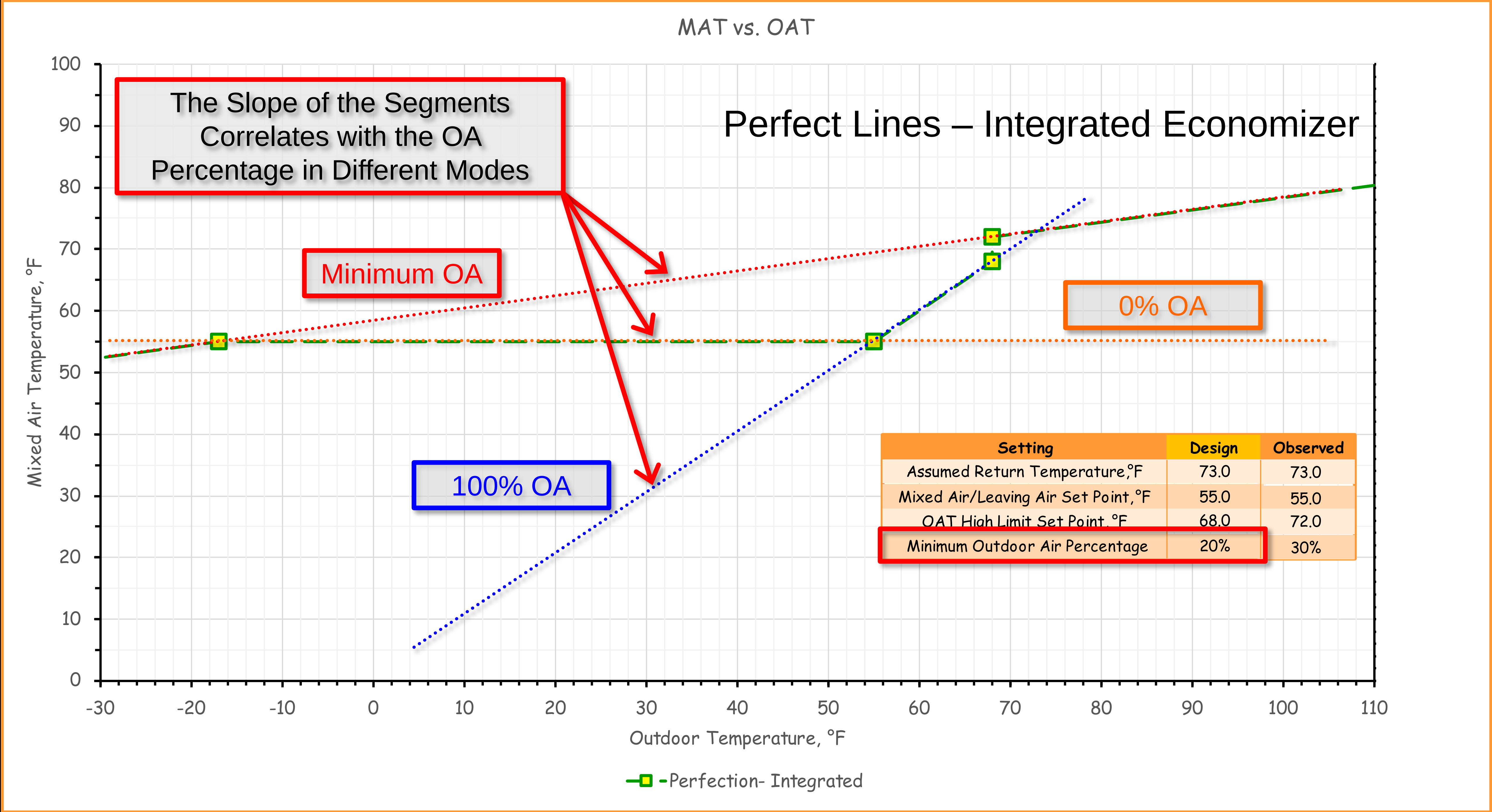


Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point,°F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%


MAT vs. OAT
Perfect Lines – Integrated Economizer
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
The MAT Set Point is Reflected in This Segment of the Perfect Lines
Setting
Design
Observed
Assumed Return Temperature,°F
73.0
73.0
Mixed Air/Leaving Air Set Point,°F
55.0
55.0
OAT High Limit Set Point,°F
68.0
72.0
Minimum Outdoor Air Percentage
20%
30%
Perfection- Integrated

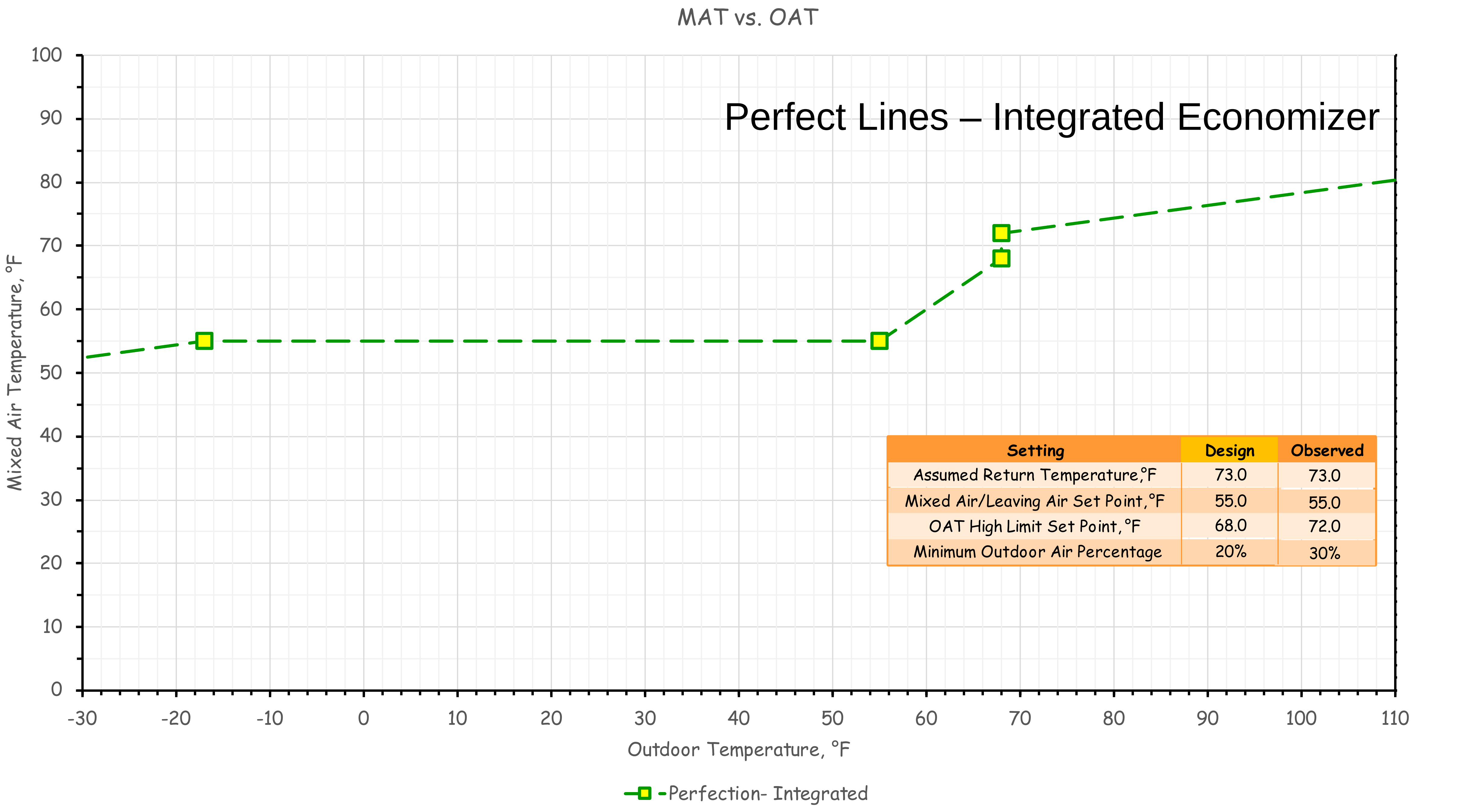


Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point,°F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%

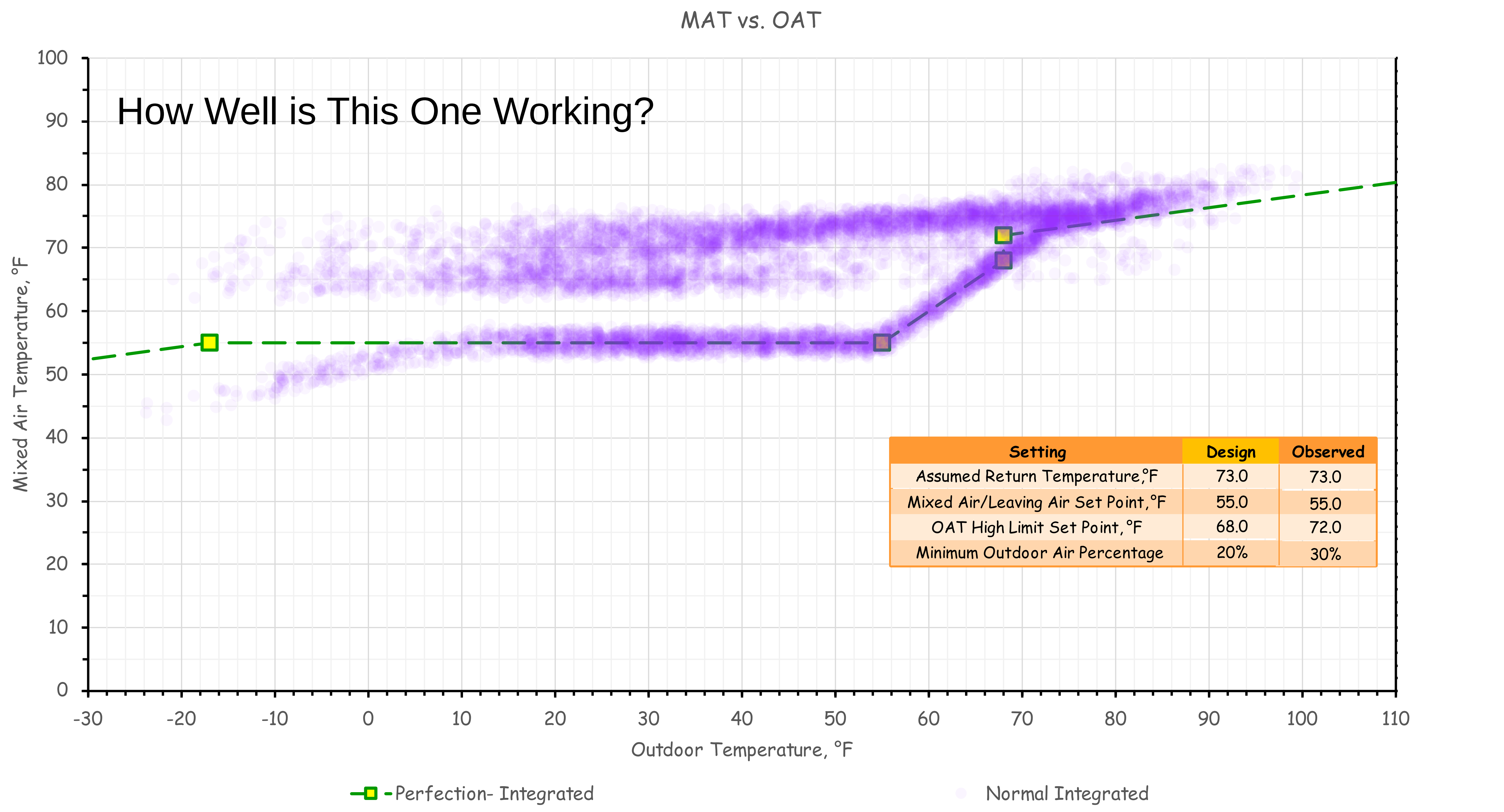


MAT vs. OAT
The Slope of the Segments Correlates with the OA Percentage in Different Modes
Perfect Lines – Integrated Economizer
Minimum OA
0% OA
100% OA
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Setting | Design | Observed
Assumed Return Temperature,°F | 73.0 | 73.0
Mixed Air/Leaving Air Set Point,°F | 55.0 | 55.0
OAT High Limit Set Point,°F | 68.0 | 72.0
Minimum Outdoor Air Percentage | 20% | 30%

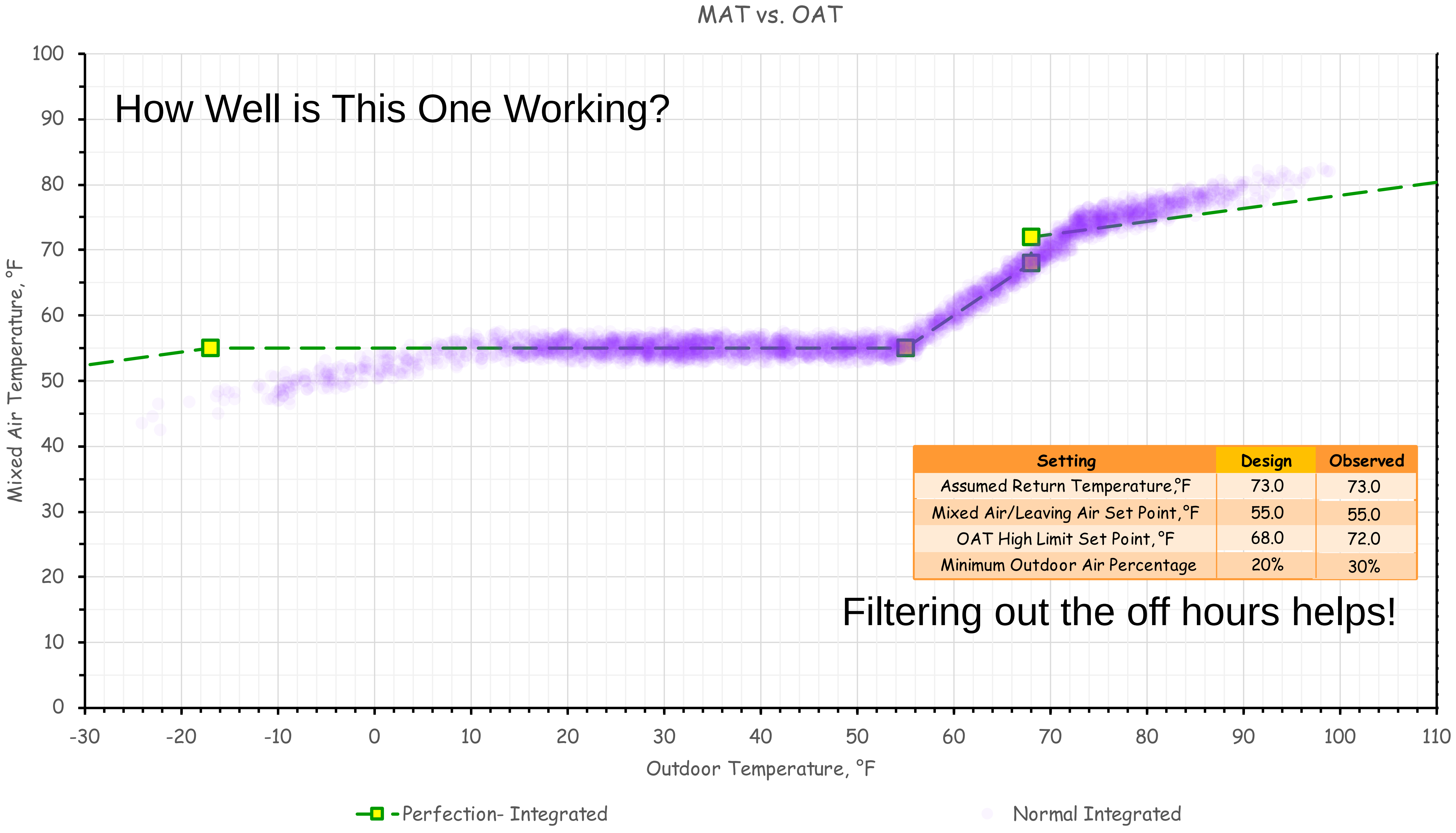
Perfect Lines – Integrated Economizer



Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point,°F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%



Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point, °F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%

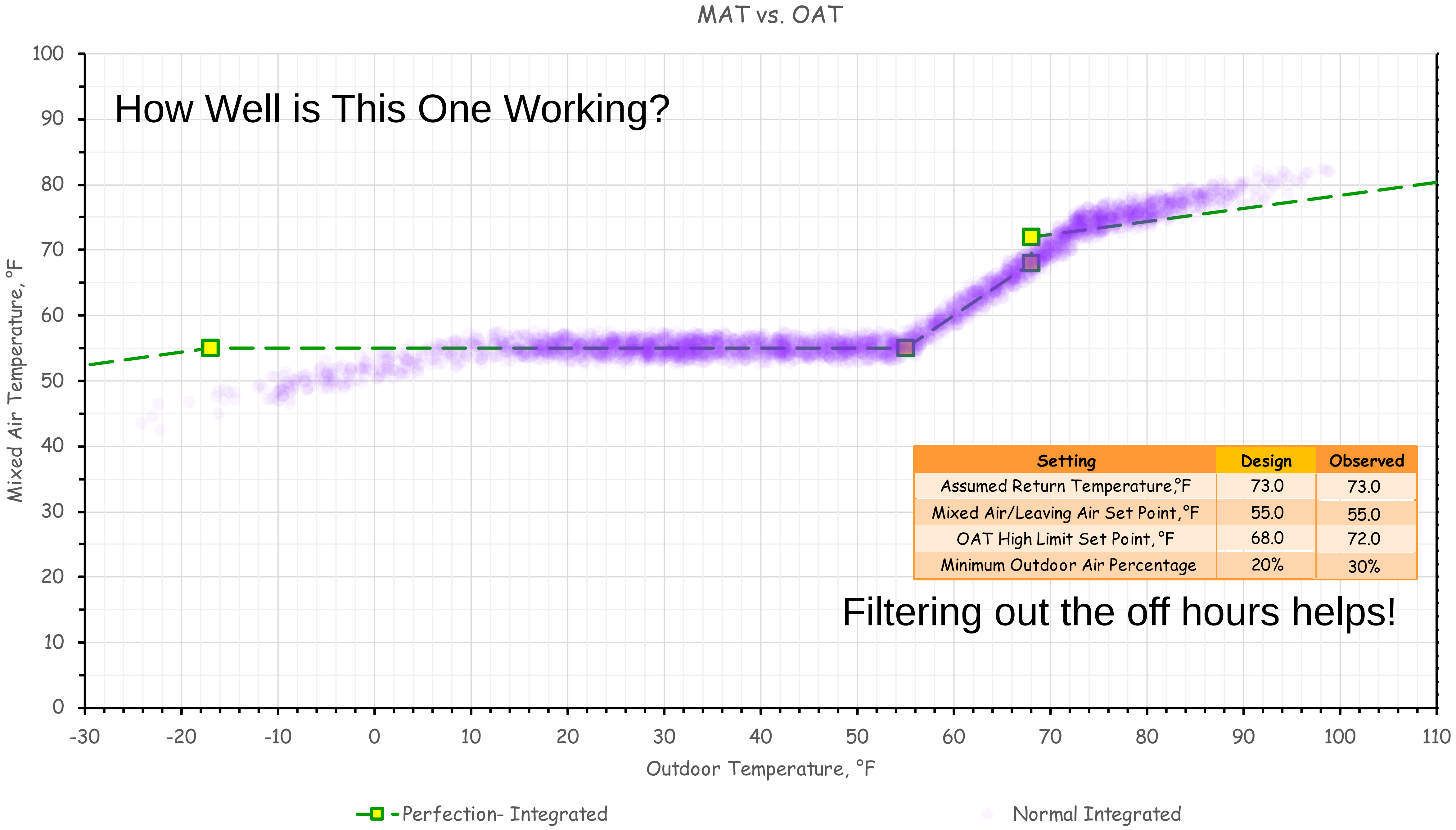


How Well is This One Working?

Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point,°F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%

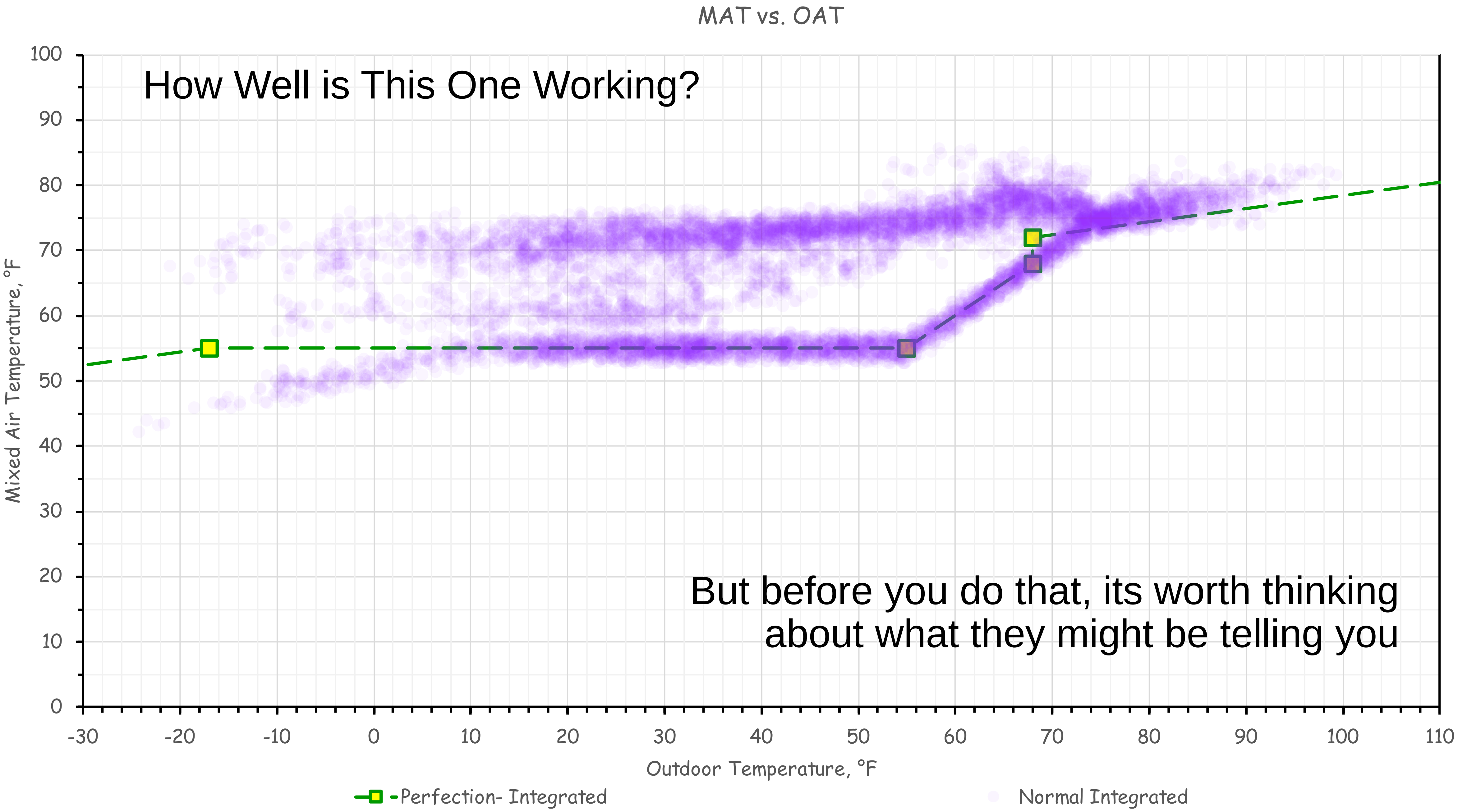
Filtering out the off hours helps!

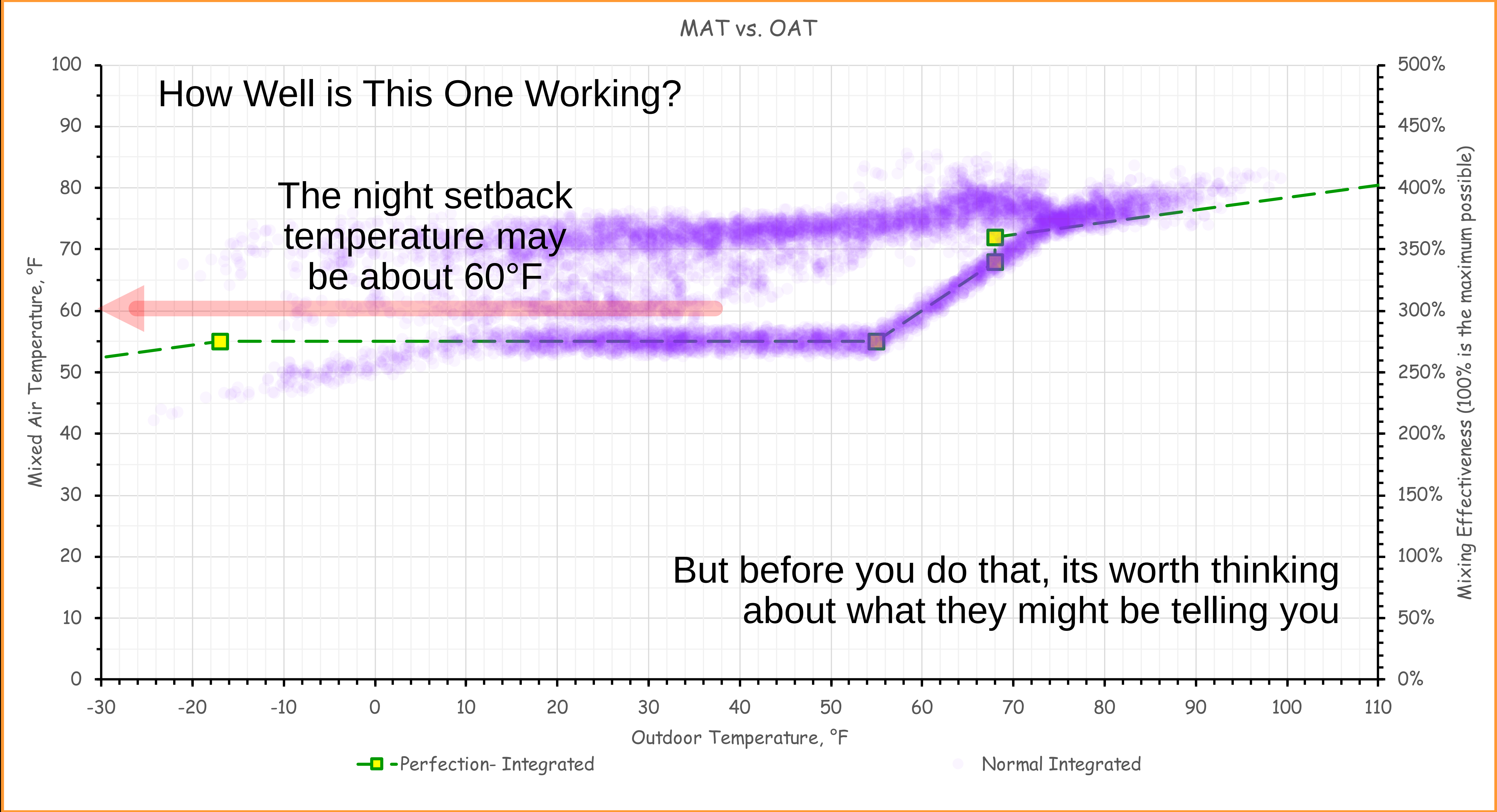
How Well is This One Working?



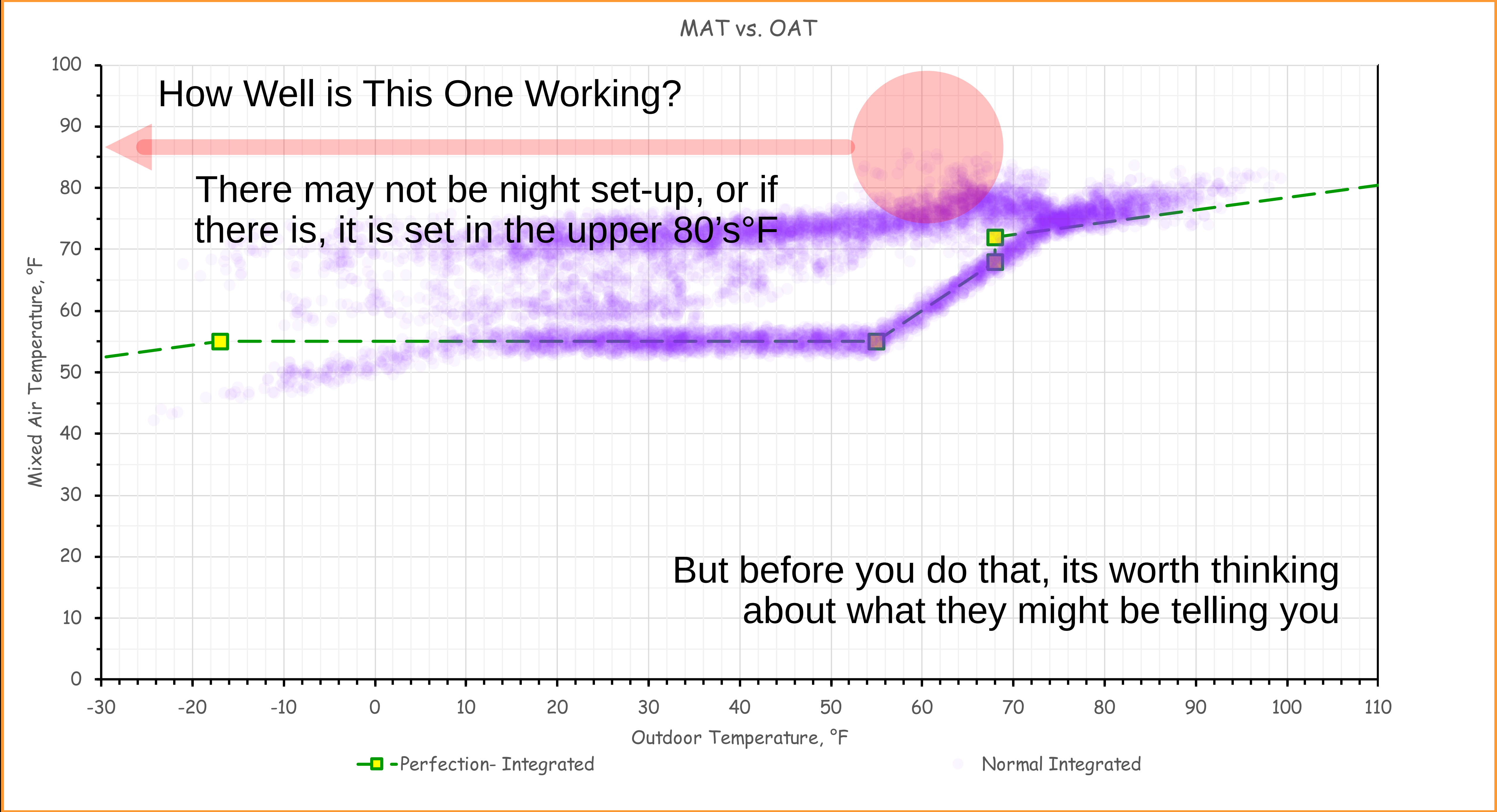
Setting	Design	Observed
Assumed Return Temperature,°F	73.0	73.0
Mixed Air/Leaving Air Set Point,°F	55.0	55.0
OAT High Limit Set Point,°F	68.0	72.0
Minimum Outdoor Air Percentage	20%	30%

Filtering out the off hours helps!

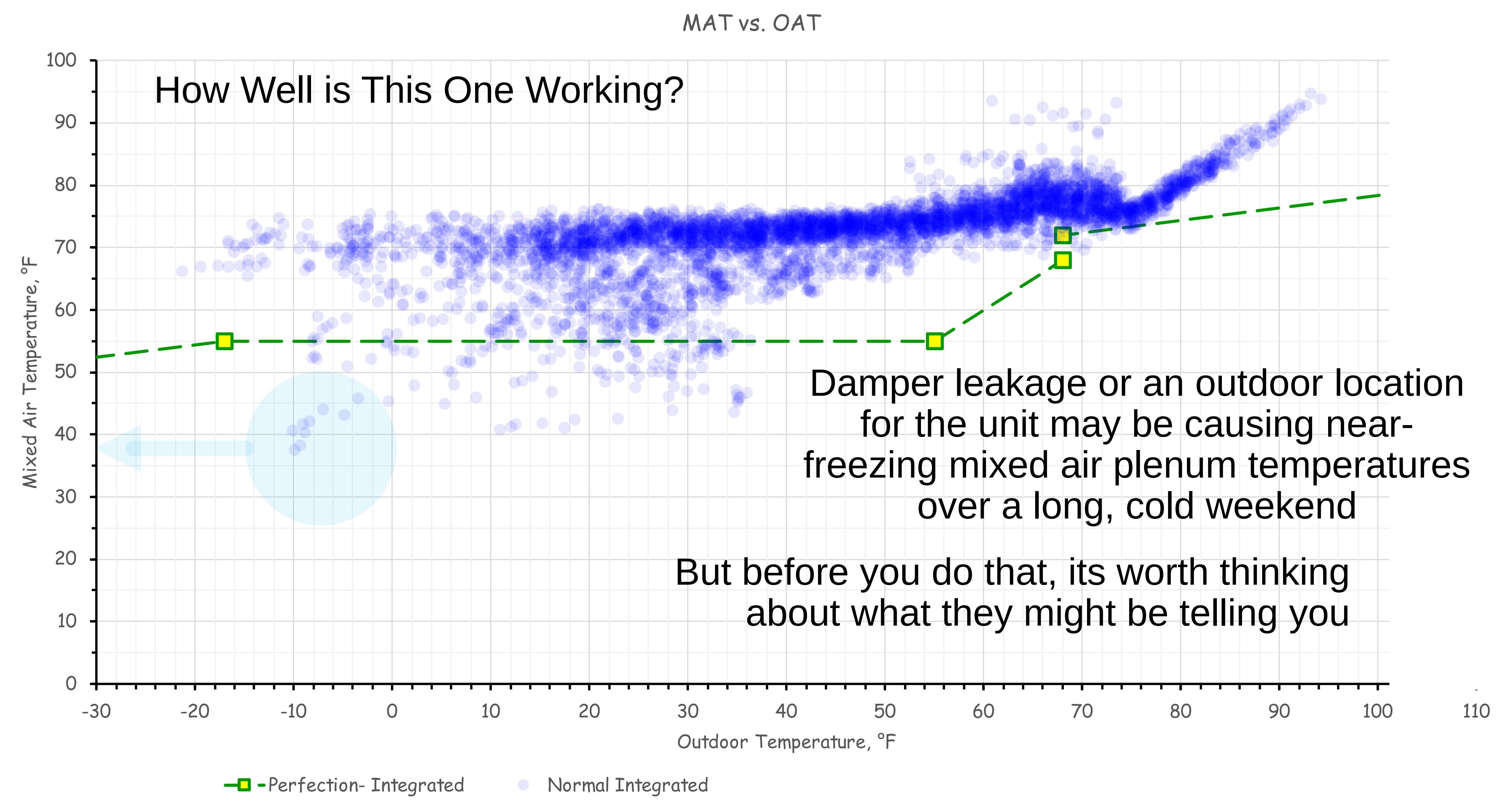

MAT vs. OAT
How Well is This One Working?
But before you do that, its worth thinking
about what they might be telling you
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated

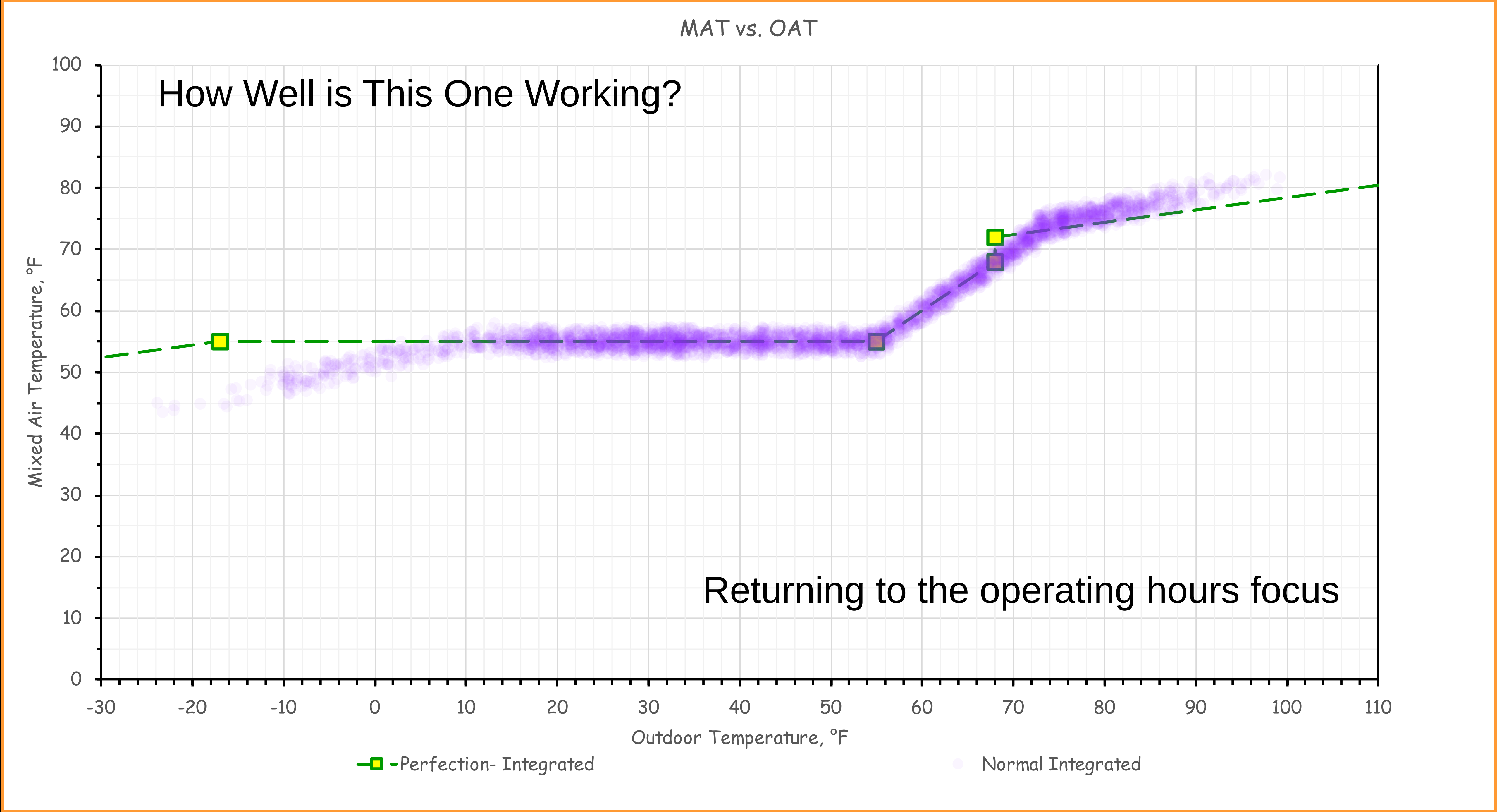


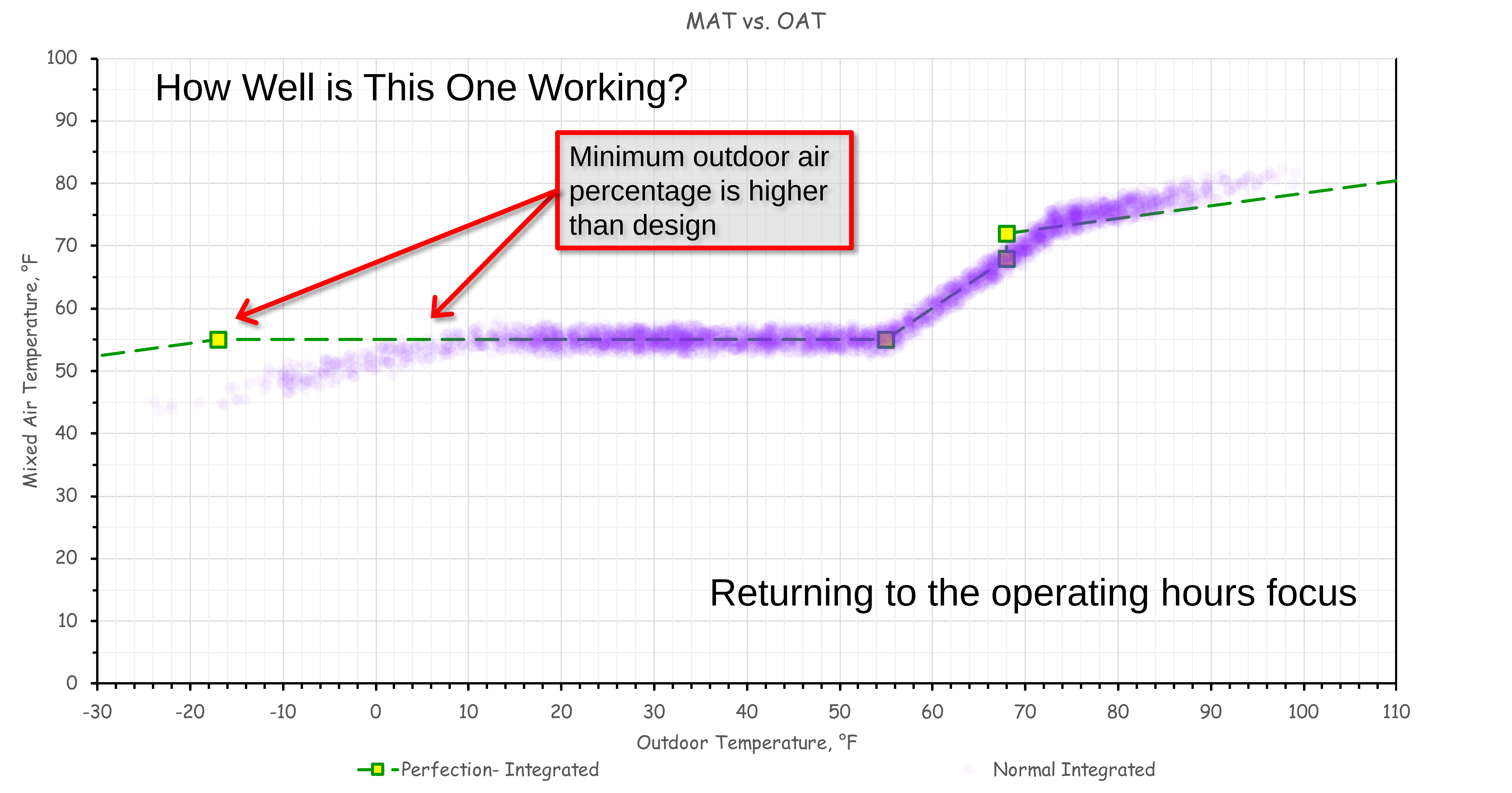
MAT vs. OAT
How Well is This One Working?
The night setback temperature may be about 60°F
But before you do that, its worth thinking about what they might be telling you
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110



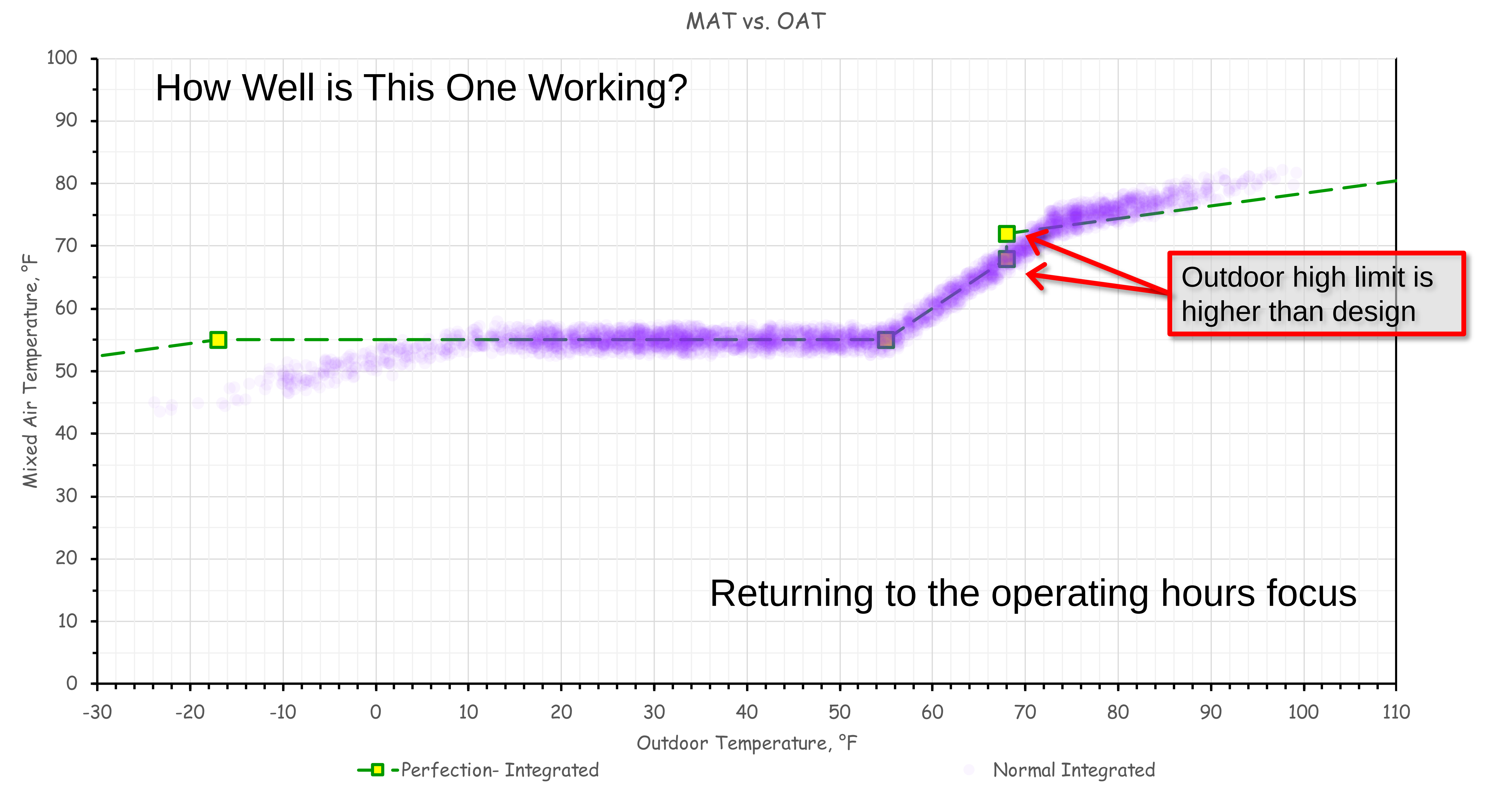
MAT vs. OAT
How Well is This One Working?
There may not be night set-up, or if there is, it is set in the upper 80's°F
But before you do that, its worth thinking about what they might be telling you
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated

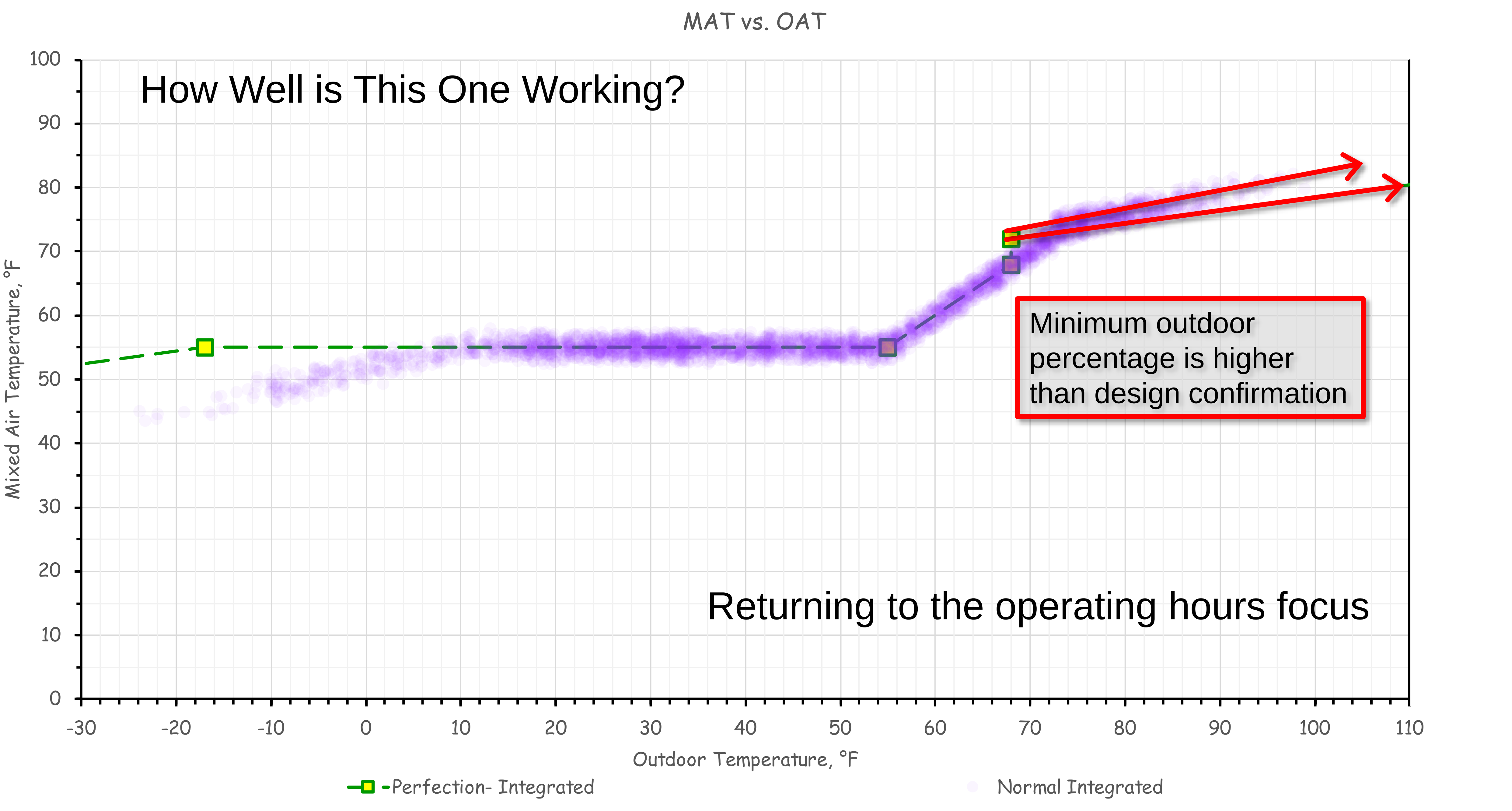

MAT vs. OAT
How Well is This One Working?
Damper leakage or an outdoor location for the unit may be causing near-freezing mixed air plenum temperatures over a long, cold weekend
But before you do that, its worth thinking about what they might be telling you
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Normal Integrated


MAT vs. OAT
How Well is This One Working?
Returning to the operating hours focus
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Normal Integrated

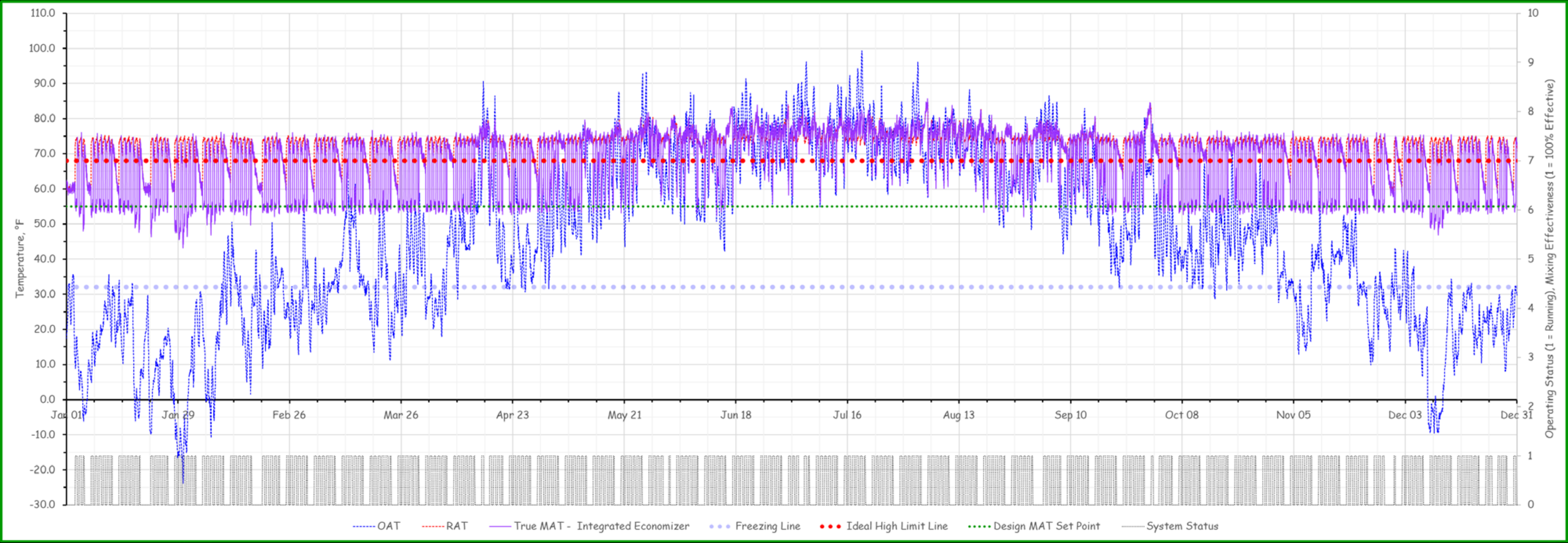


MAT vs. OAT
How Well is This One Working?
Minimum outdoor air percentage is higher than design
Returning to the operating hours focus
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Normal Integrated

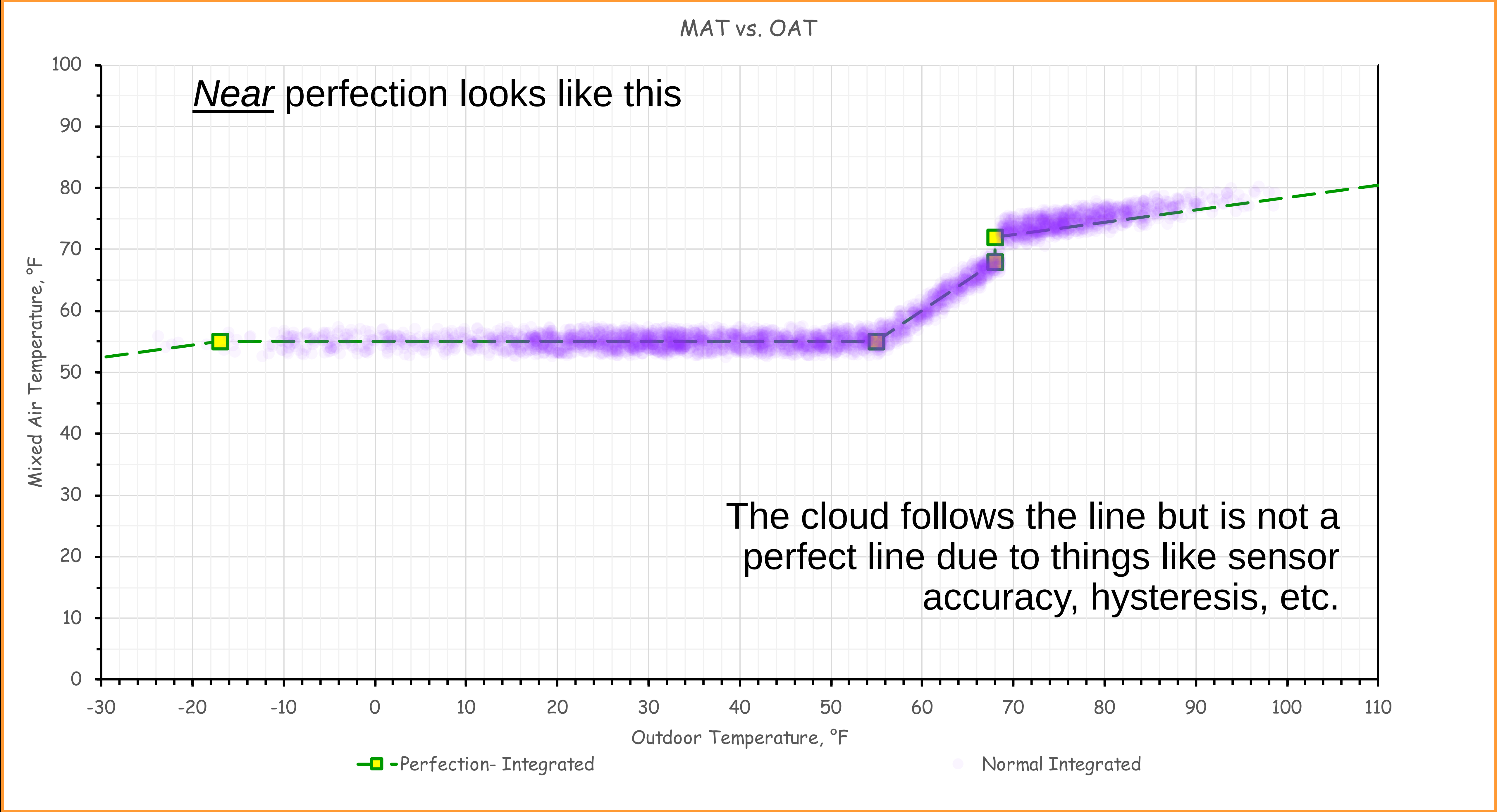

MAT vs. OAT
How Well is This One Working?
Outdoor high limit is higher than design
Returning to the operating hours focus
Mixed Air Temperature, °F
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110


MAT vs. OAT
How Well is This One Working?
Minimum outdoor percentage is higher than design confirmation
Returning to the operating hours focus
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Normal Integrated

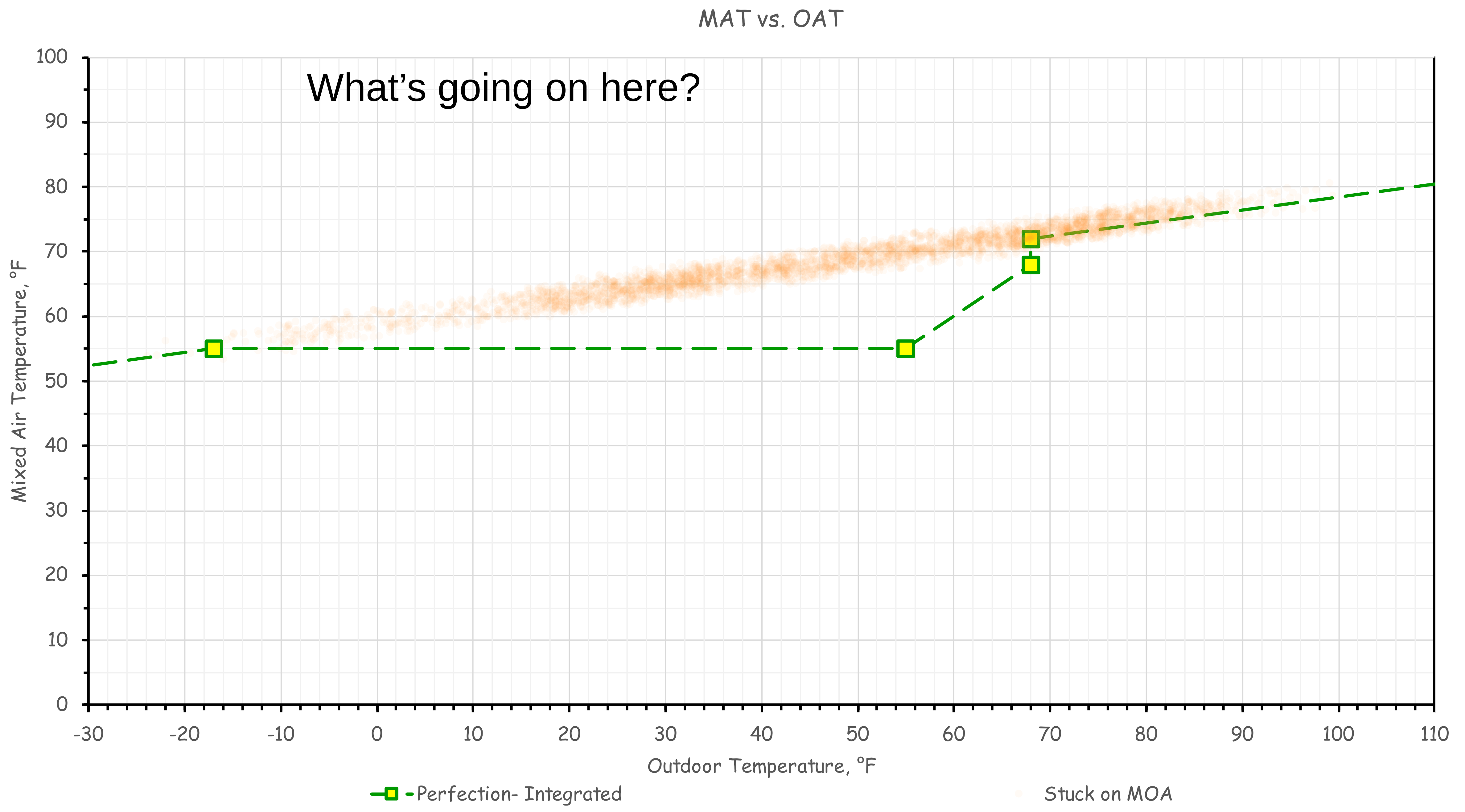
How Well is This One Working?

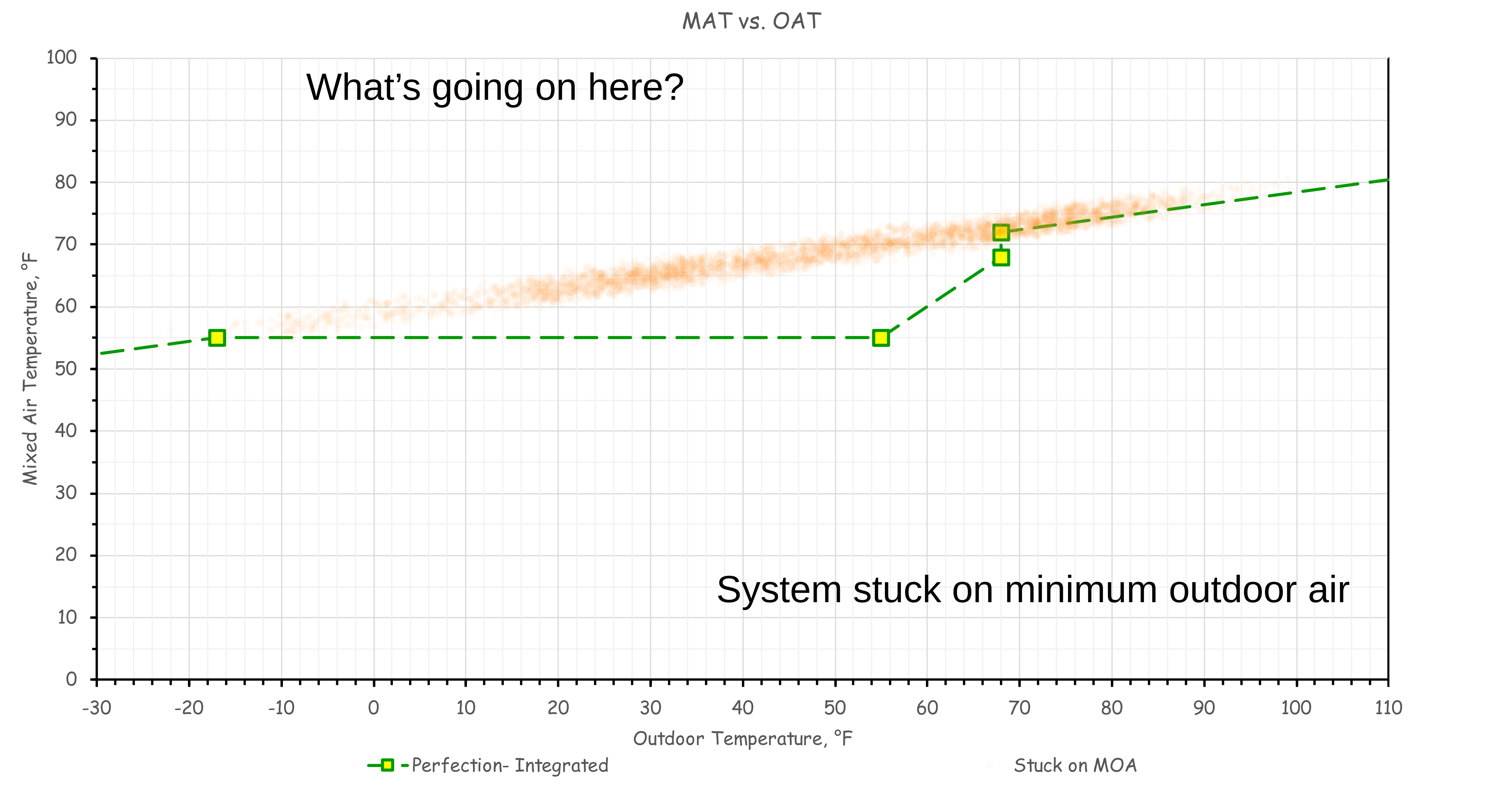


Some things may be harder to see in a time series vs. the diagnostic plot we are using



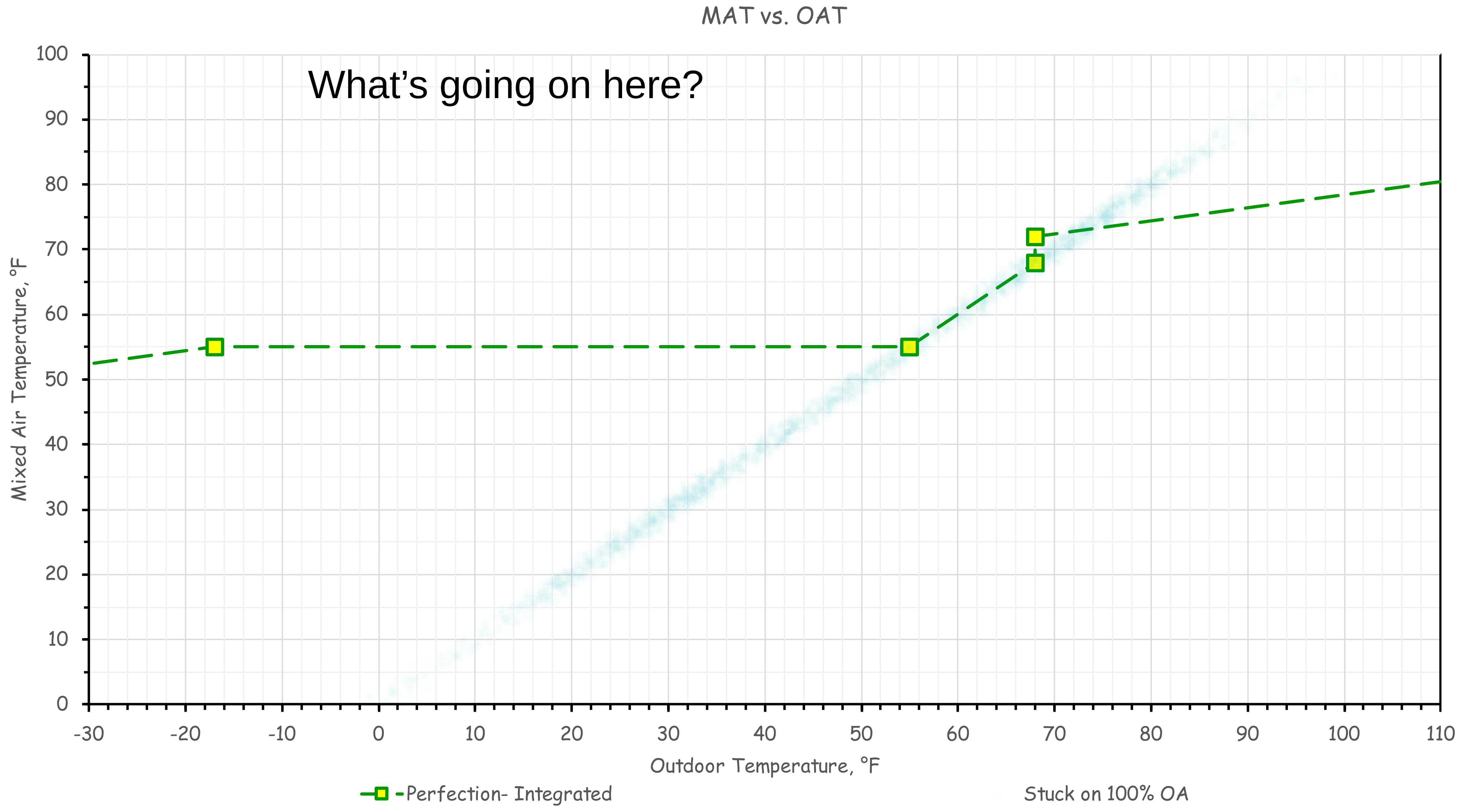
MAT vs. OAT
Near perfection looks like this
The cloud follows the line but is not a perfect line due to things like sensor accuracy, hysteresis, etc.
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated

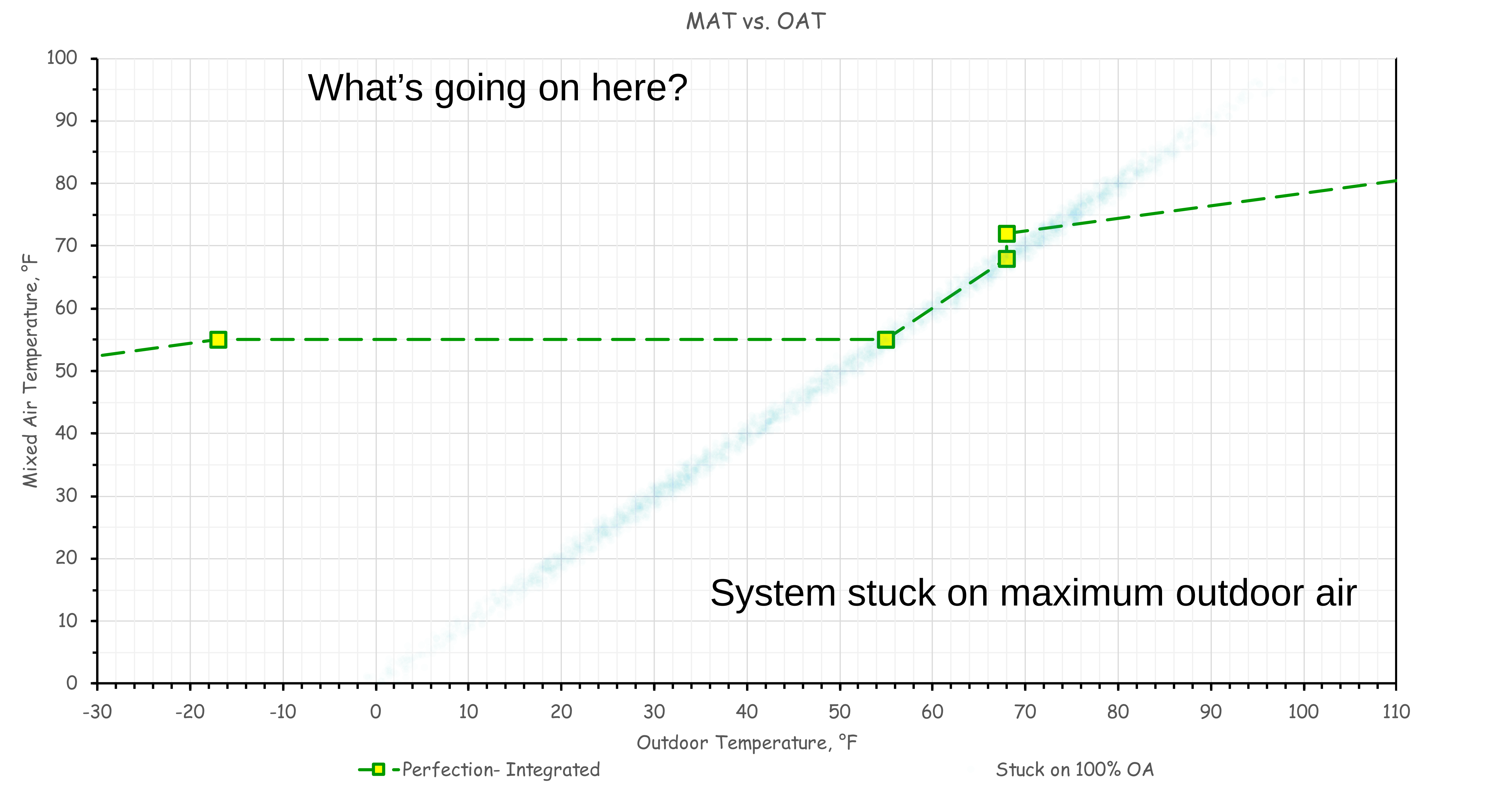

MAT vs. OAT
What’s going on here?
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Stuck on MOA

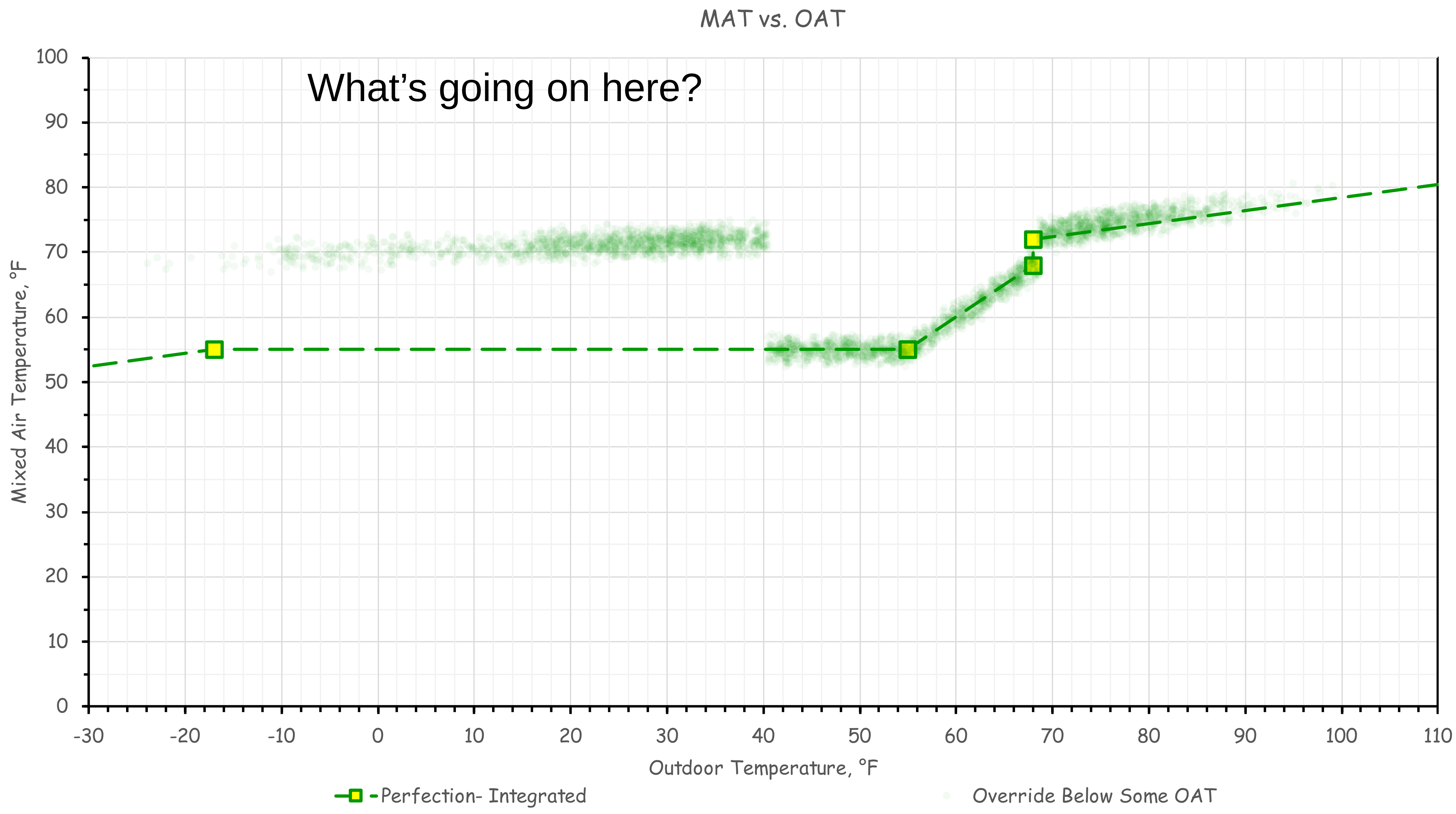


MAT vs. OAT
What's going on here?
System stuck on minimum outdoor air
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Stuck on MOA

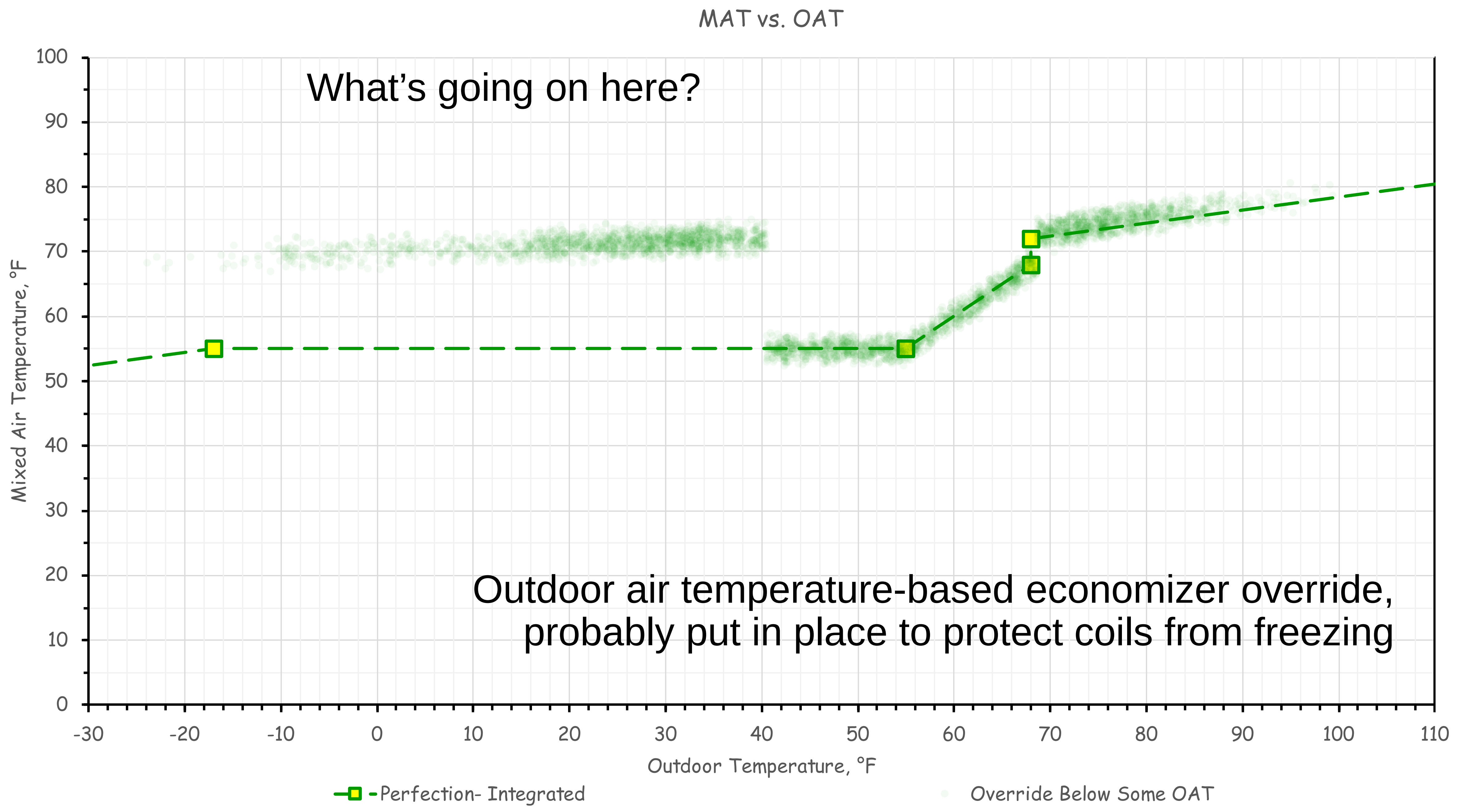
What's going on here?

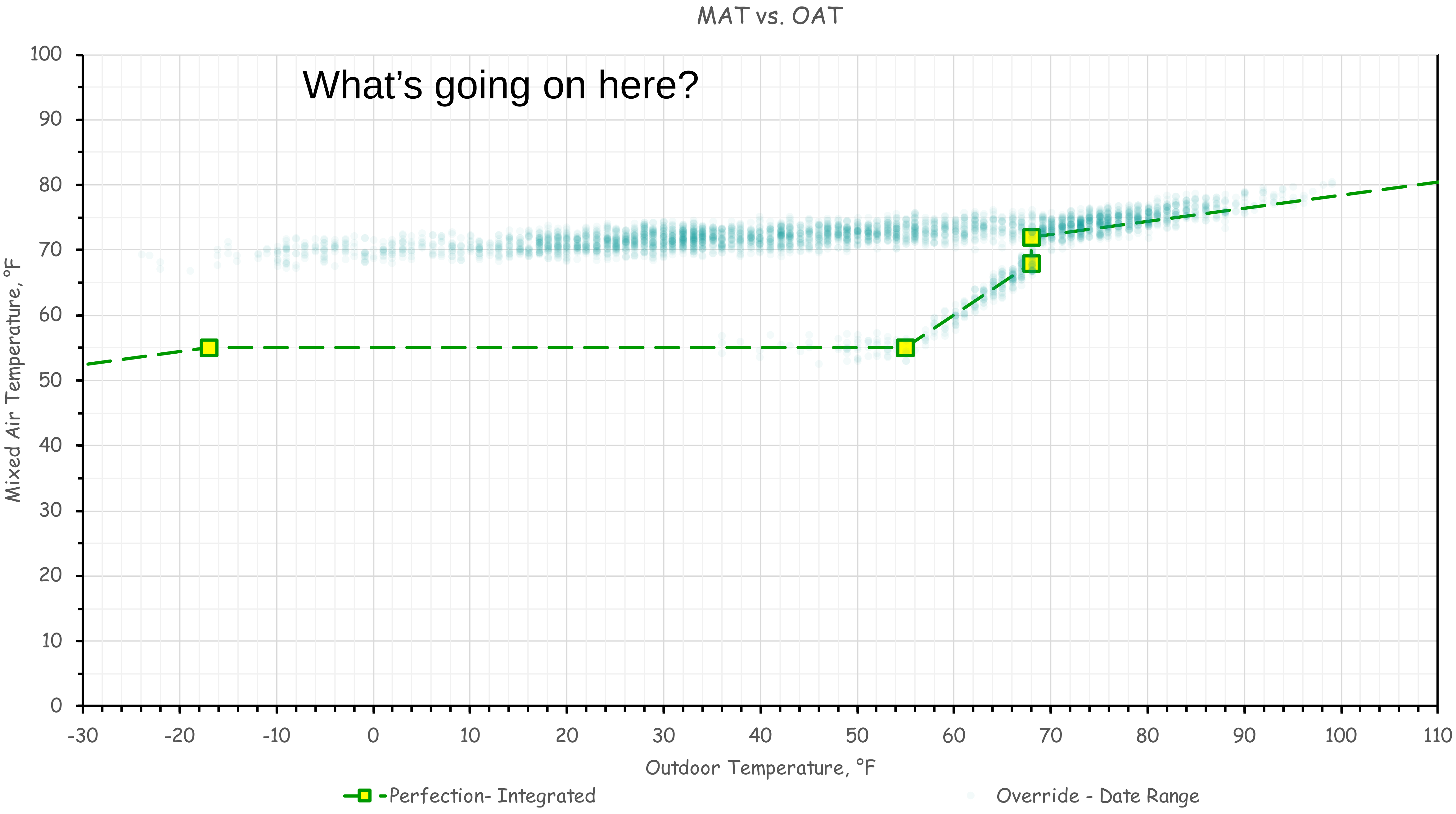



MAT vs. OAT
What’s going on here?
System stuck on maximum outdoor air
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
-Perfection- Integrated
Stuck on 100% OA

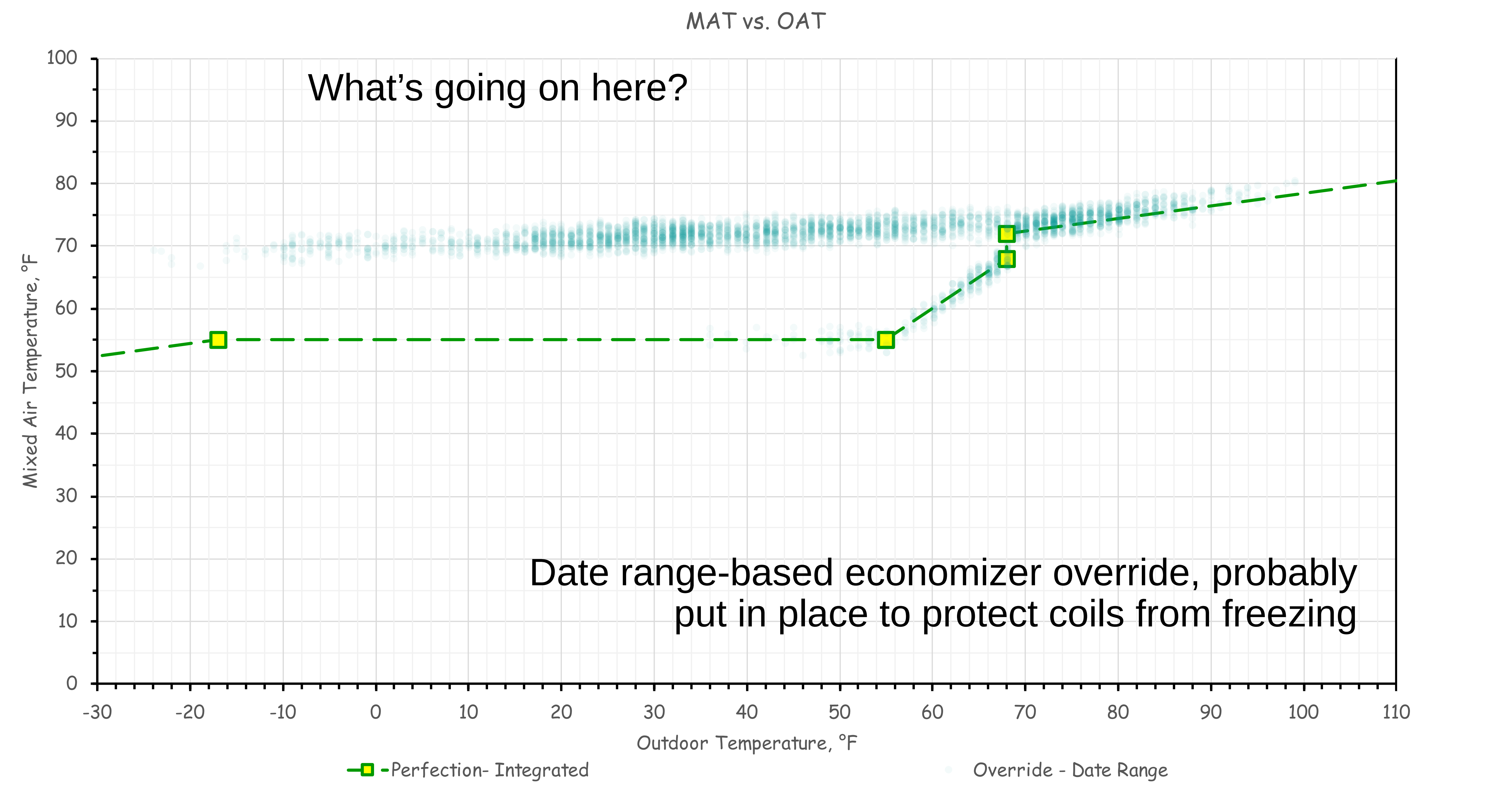


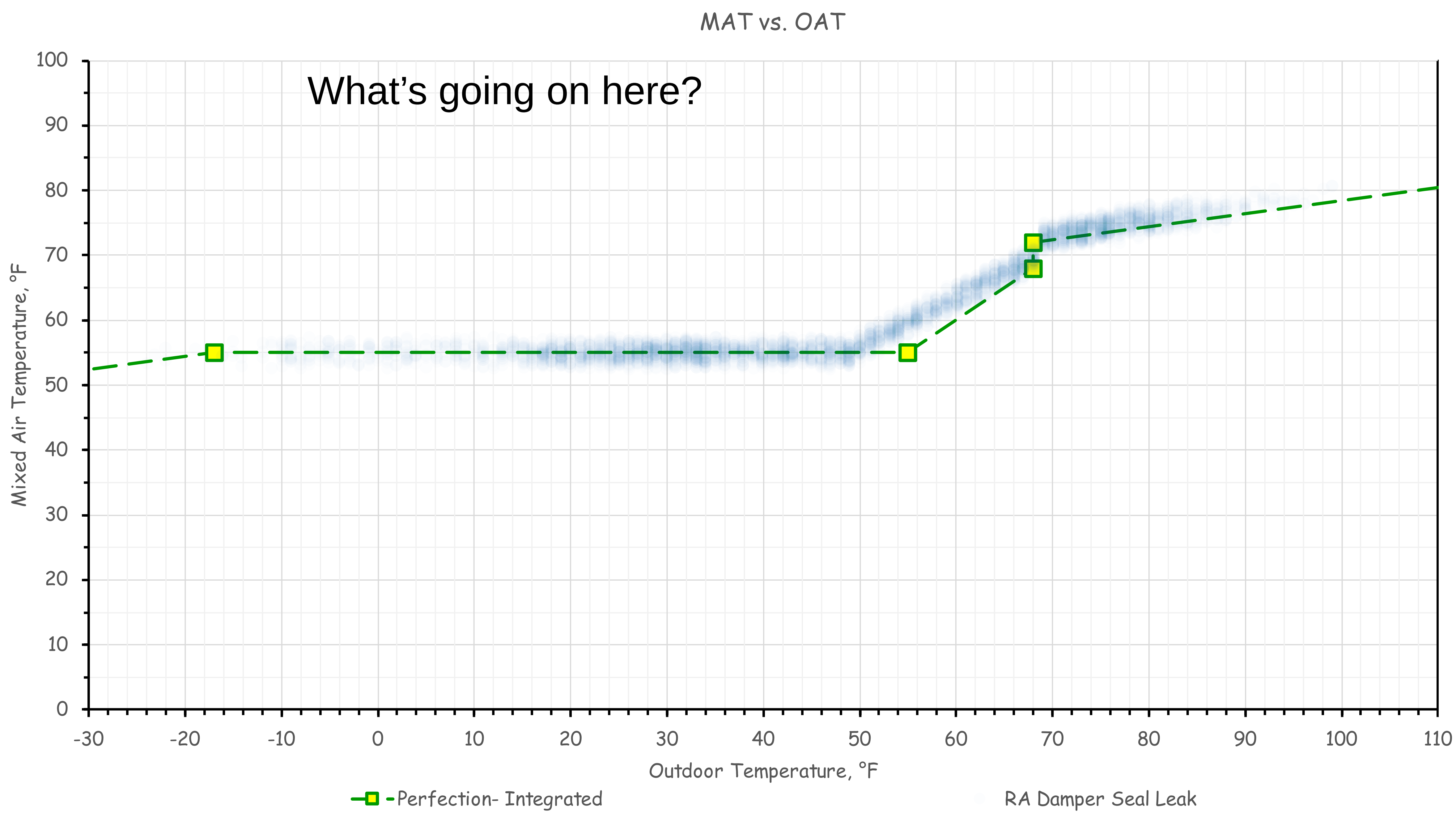
MAT vs. OAT
What’s going on here?
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Override Below Some OAT


MAT vs. OAT
What's going on here?
Outdoor air temperature-based economizer override,
probably put in place to protect coils from freezing
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Override Below Some OAT



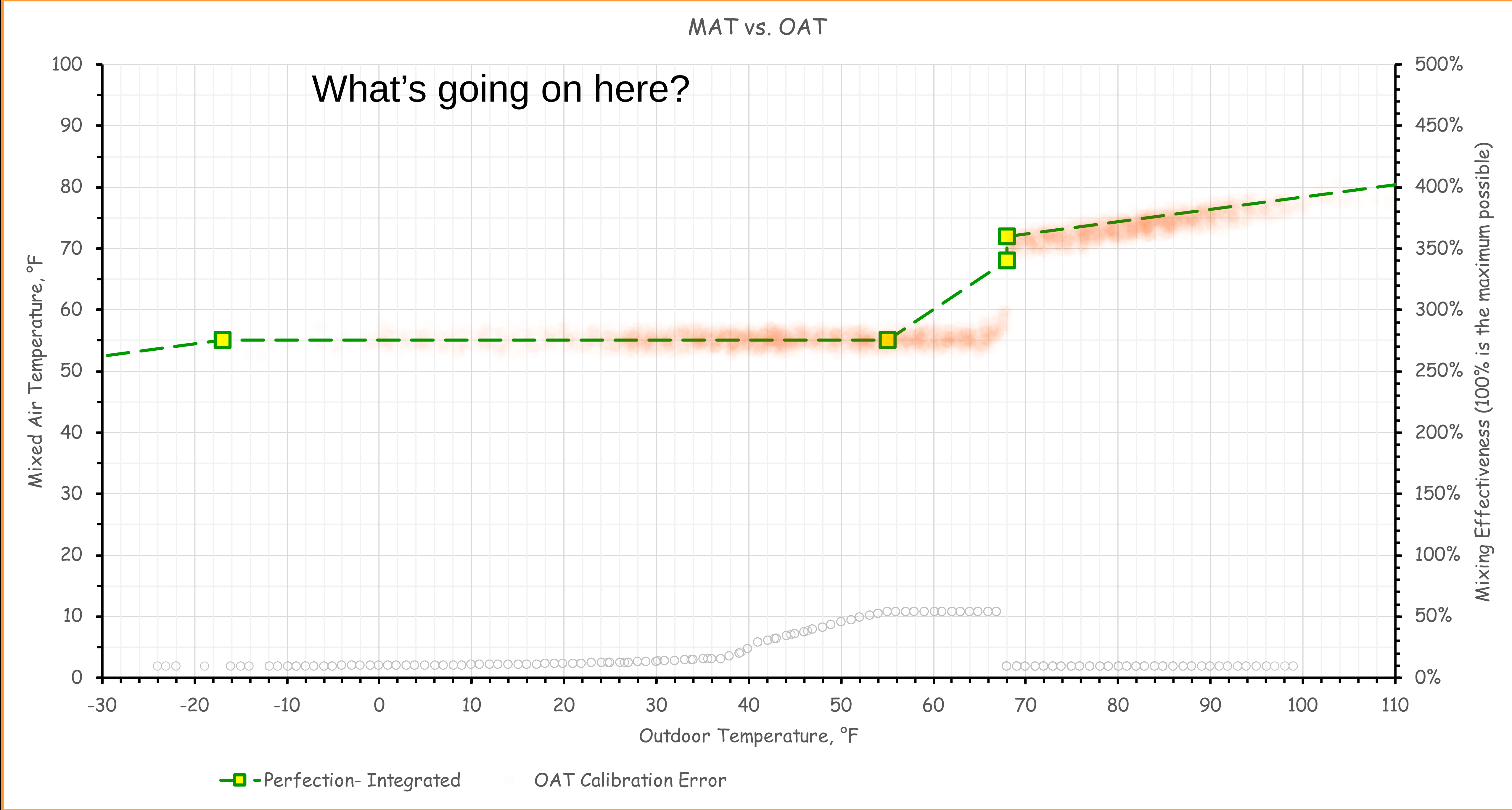
MAT vs. OAT
What's going on here?
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Override - Date Range

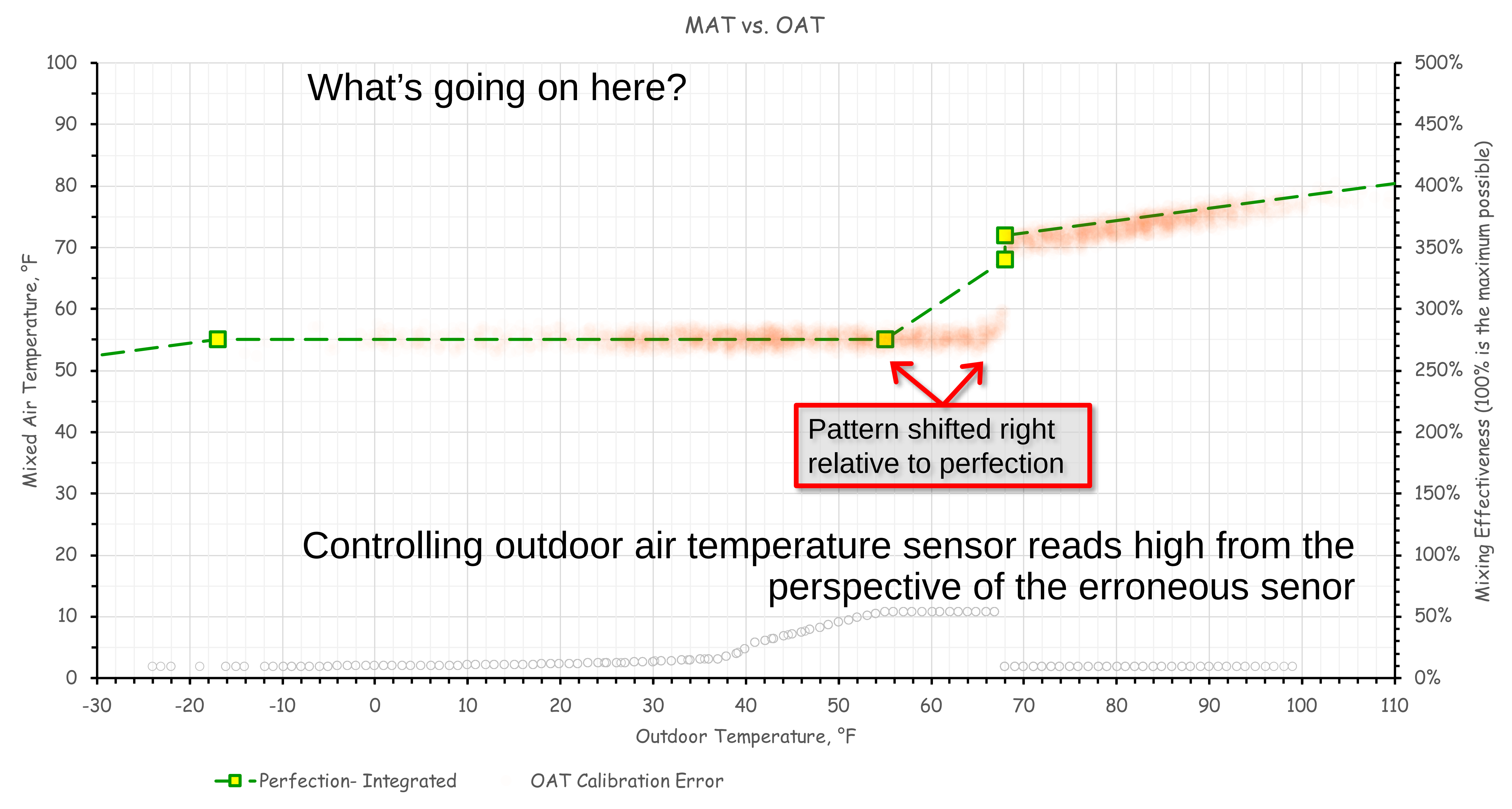

MAT vs. OAT
What's going on here?
Date range-based economizer override, probably put in place to protect coils from freezing
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Override - Date Range

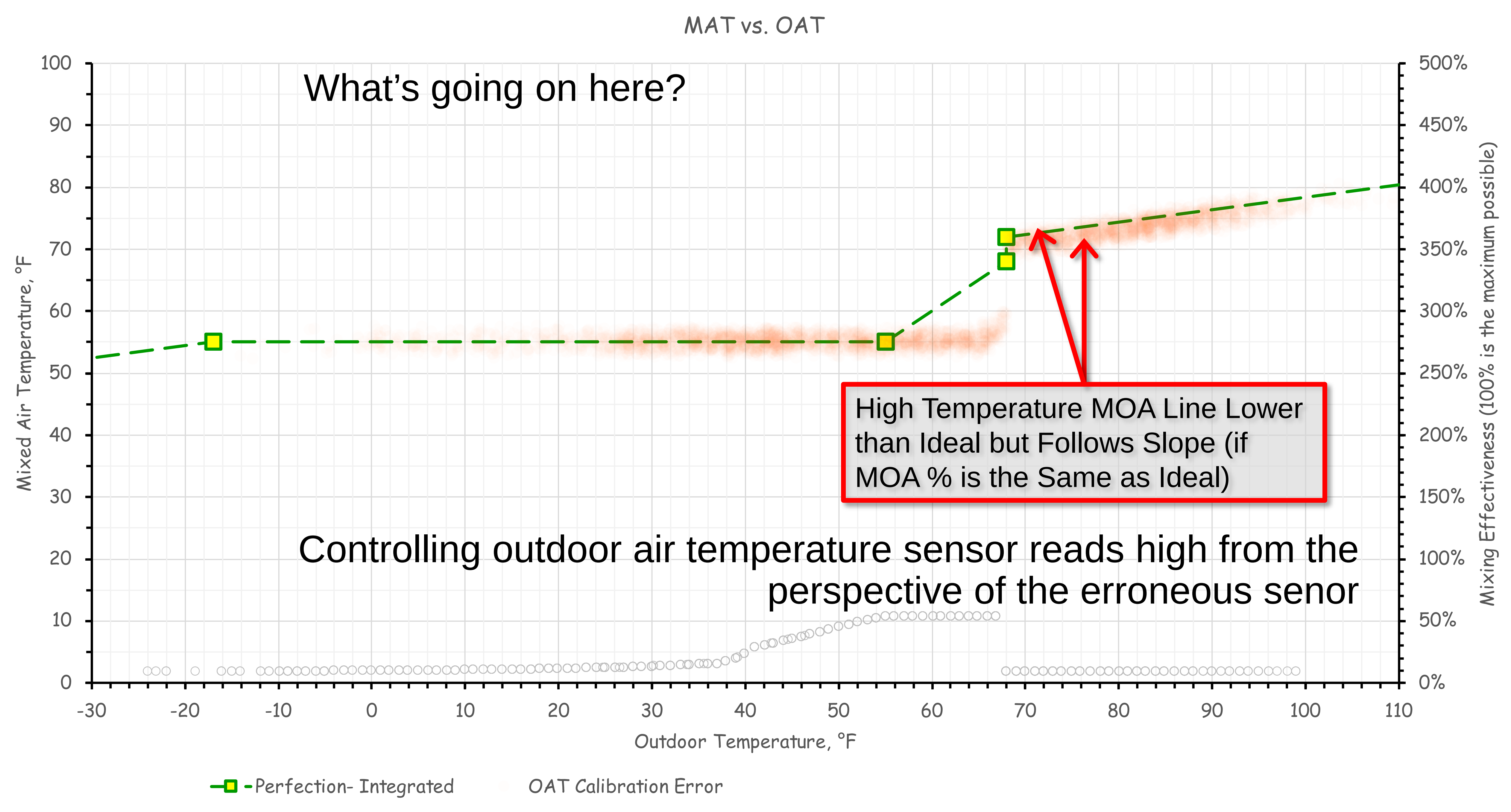


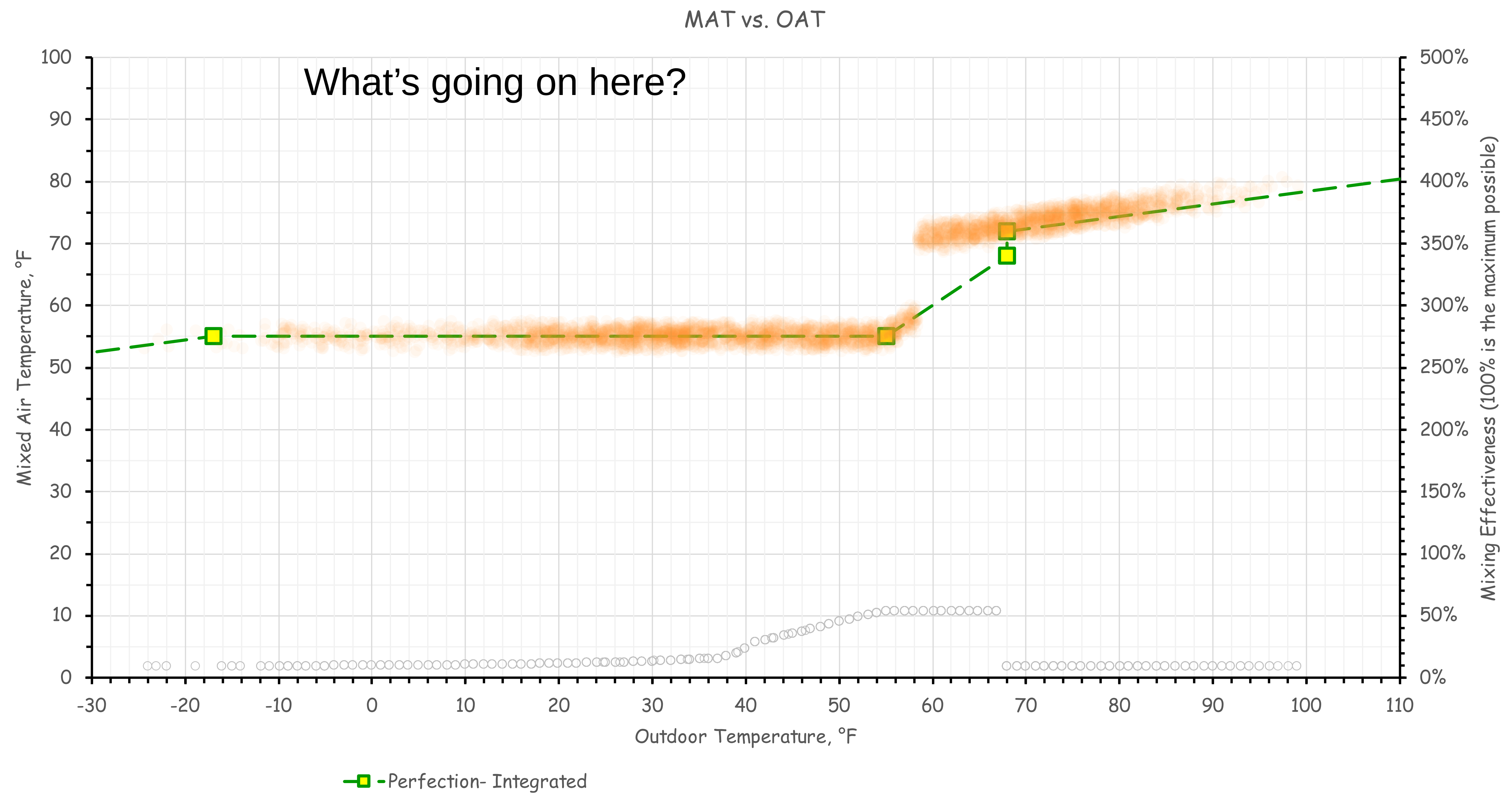
MAT vs. OAT
What's going on here?
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
RA Damper Seal Leak


MAT vs. OAT
What's going on here?
Return air damper leaking either due to missing blade seals, insufficient seating torque, jack shaft alignment issues or bent or damaged blades
Mixed Air Temperature, °F
Outdoor Temperature, °F
0
10
20
30
40
50
60
70
80
90
100
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
RA Damper Seal Leak

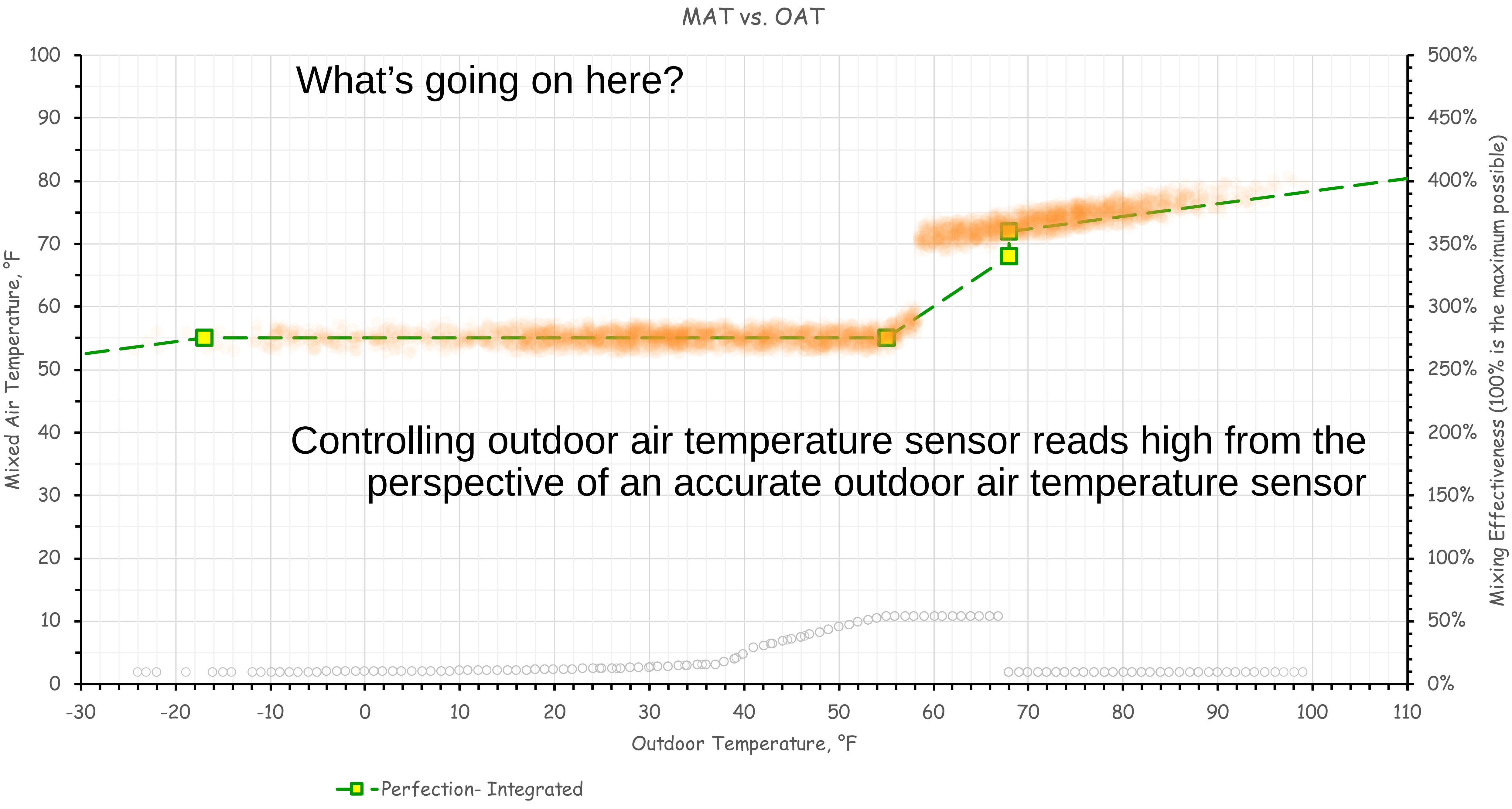

MAT vs. OAT
What's going on here?
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
OAT Calibration Error

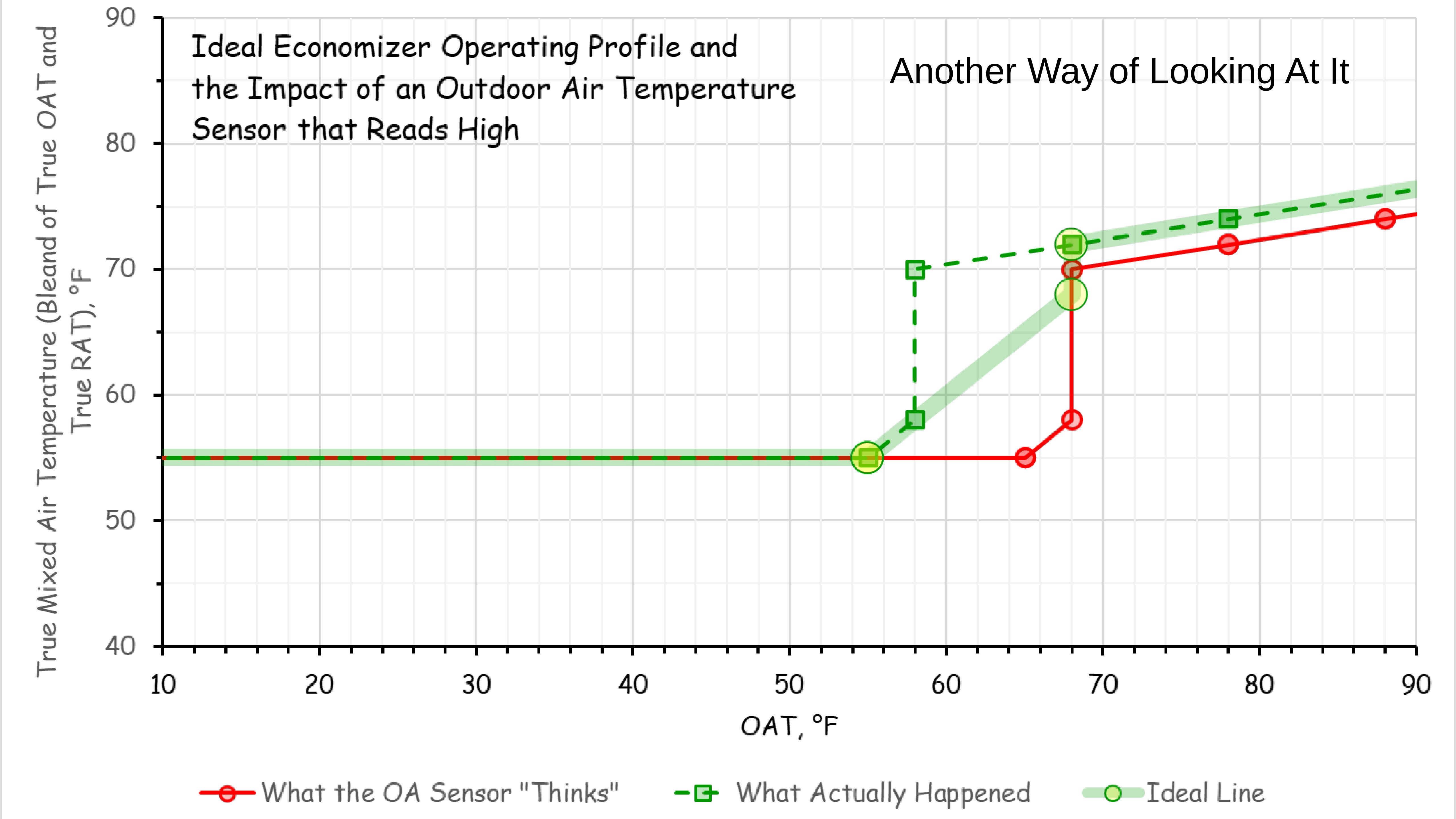

MAT vs. OAT
What's going on here?
Pattern shifted right relative to perfection
Controlling outdoor air temperature sensor reads high from the perspective of the erroneous senor
Mixed Air Temperature, °F
Outdoor Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
Perfection- Integrated
OAT Calibration Error


MAT vs. OAT
What's going on here?
High Temperature MOA Line Lower than Ideal but Follows Slope (if MOA % is the Same as Ideal)
Controlling outdoor air temperature sensor reads high from the perspective of the erroneous senor
Mixed Air Temperature, °F
Outdoor Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
Perfection- Integrated
OAT Calibration Error

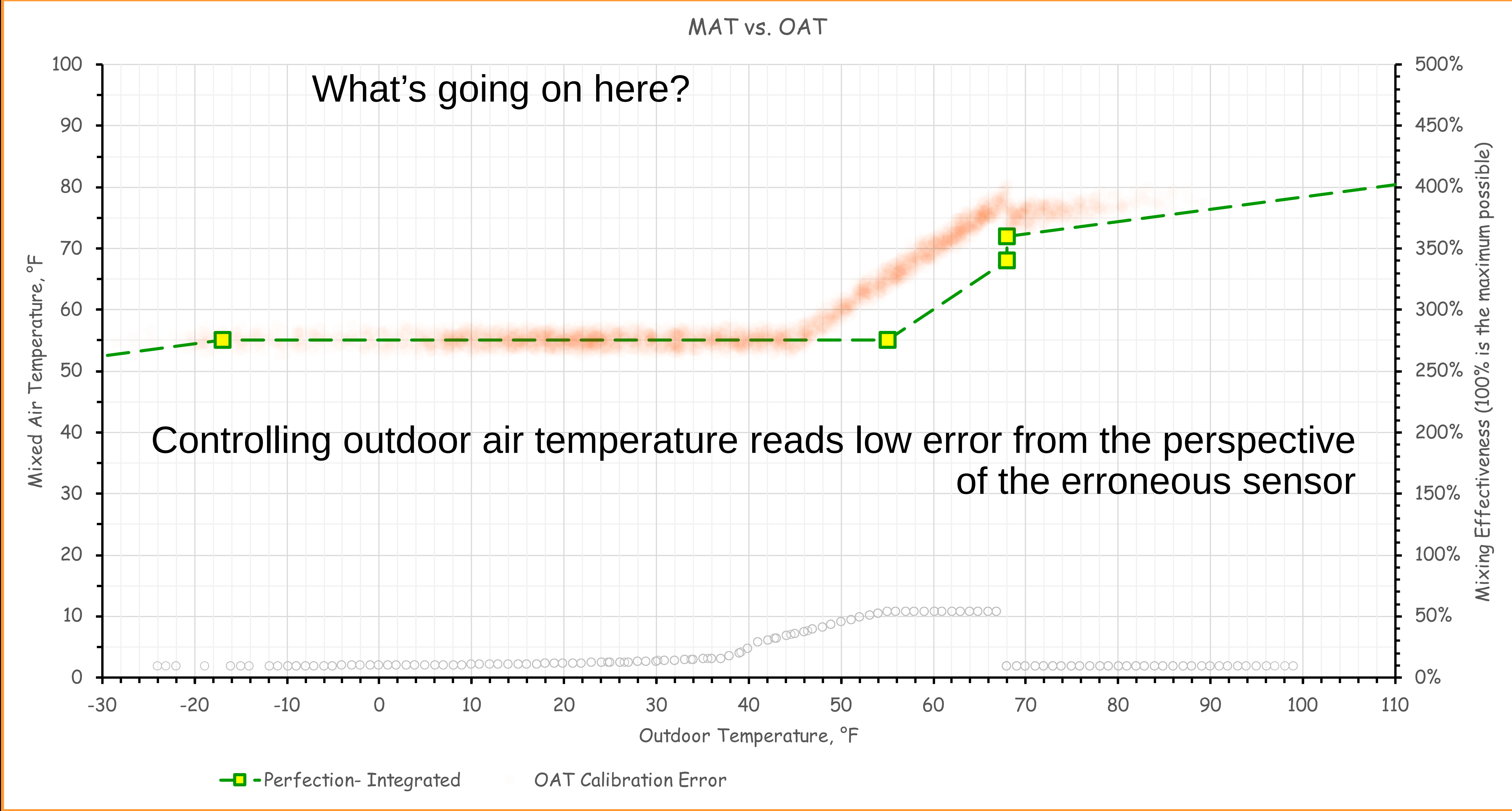


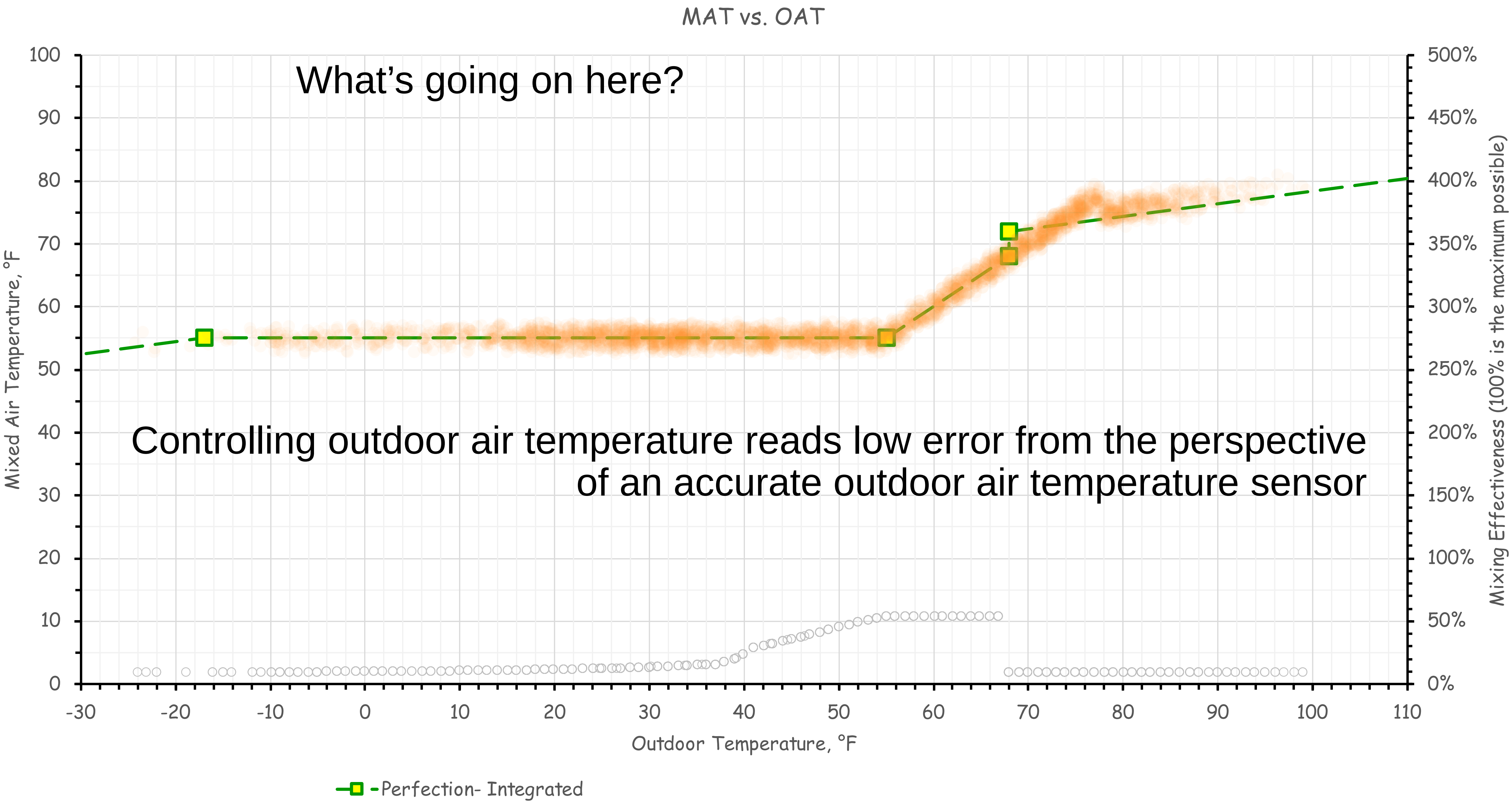
MAT vs. OAT
What's going on here?
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated

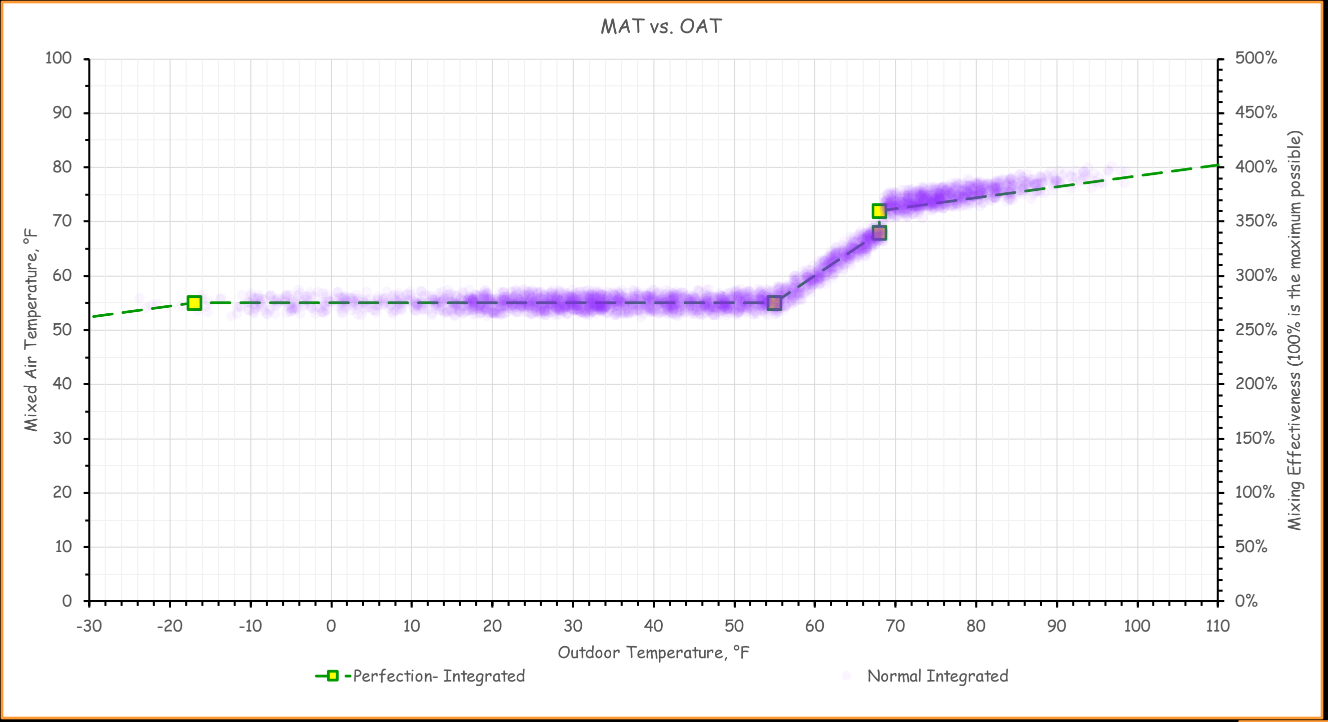

MAT vs. OAT
What's going on here?
Controlling outdoor air temperature sensor reads high from the perspective of an accurate outdoor air temperature sensor
Mixed Air Temperature, °F
Outdoor Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated



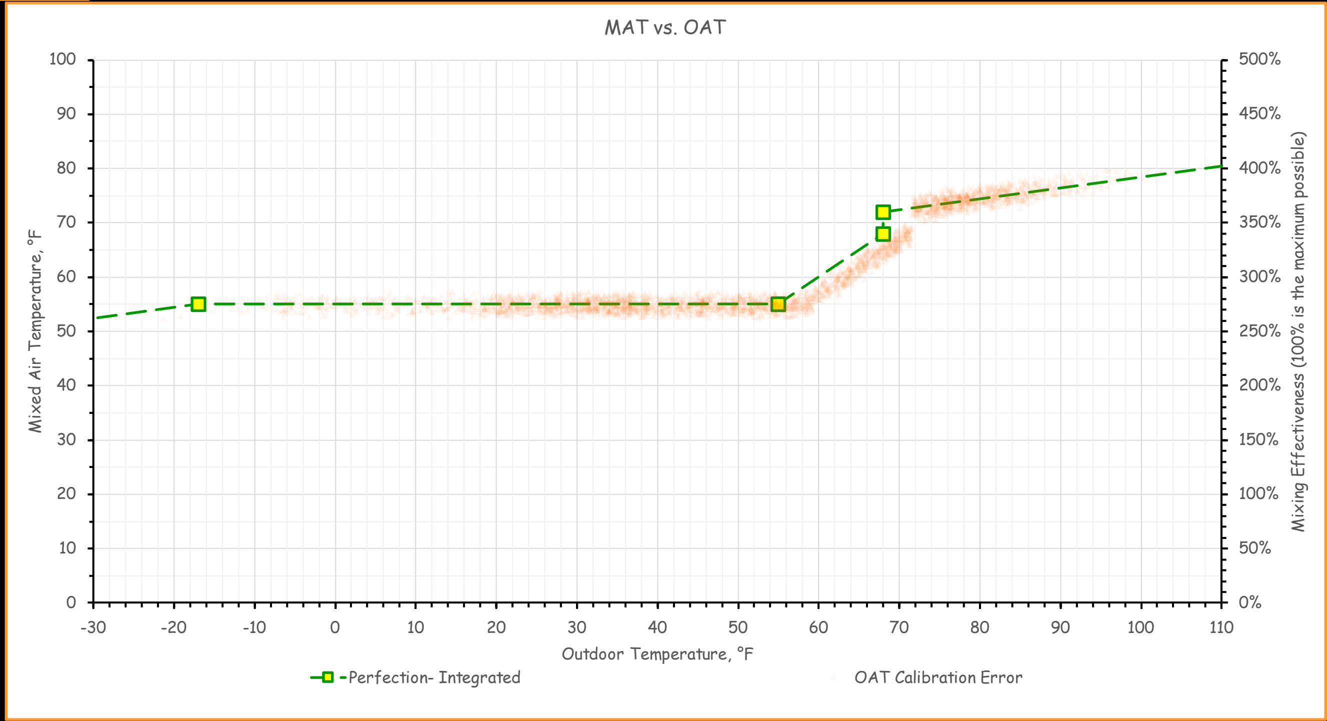
Ideal Economizer Operating Profile and the Impact of an Outdoor Air Temperature Sensor that Reads High
Another Way of Looking At It
True Mixed Air Temperature (Bleand of True OAT and True RAT), °F
90
80
70
60
50
40
10
20
30
40
50
60
70
80
90
OAT, °F
What the OA Sensor "Thinks"
What Actually Happened
Ideal Line

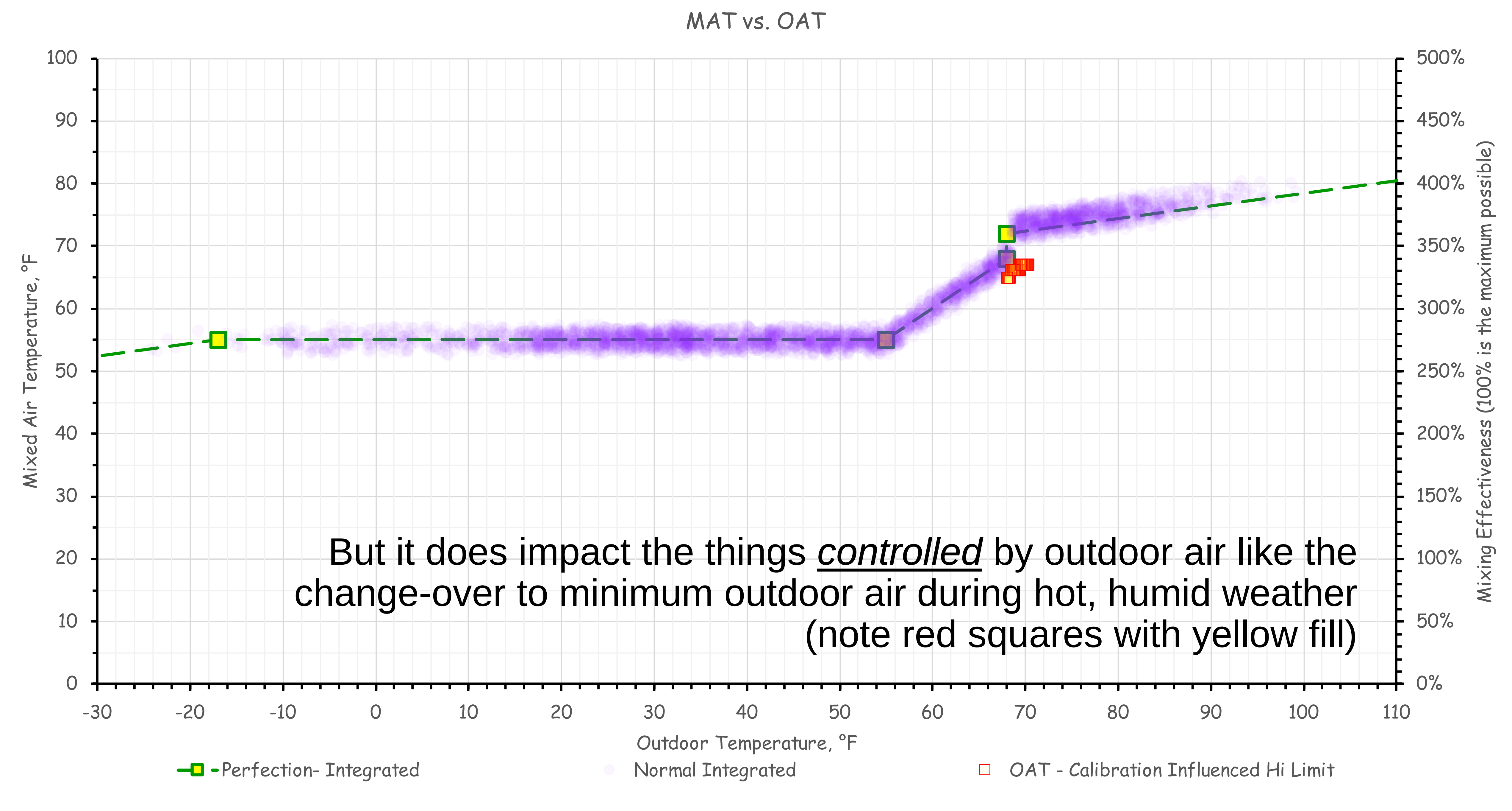

MAT vs. OAT
What’s going on here?
Controlling outdoor air temperature reads low error from the perspective of the erroneous sensor
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
OAT Calibration Error


MAT vs. OAT
What's going on here?
Controlling outdoor air temperature reads low error from the perspective of an accurate outdoor air temperature sensor
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated

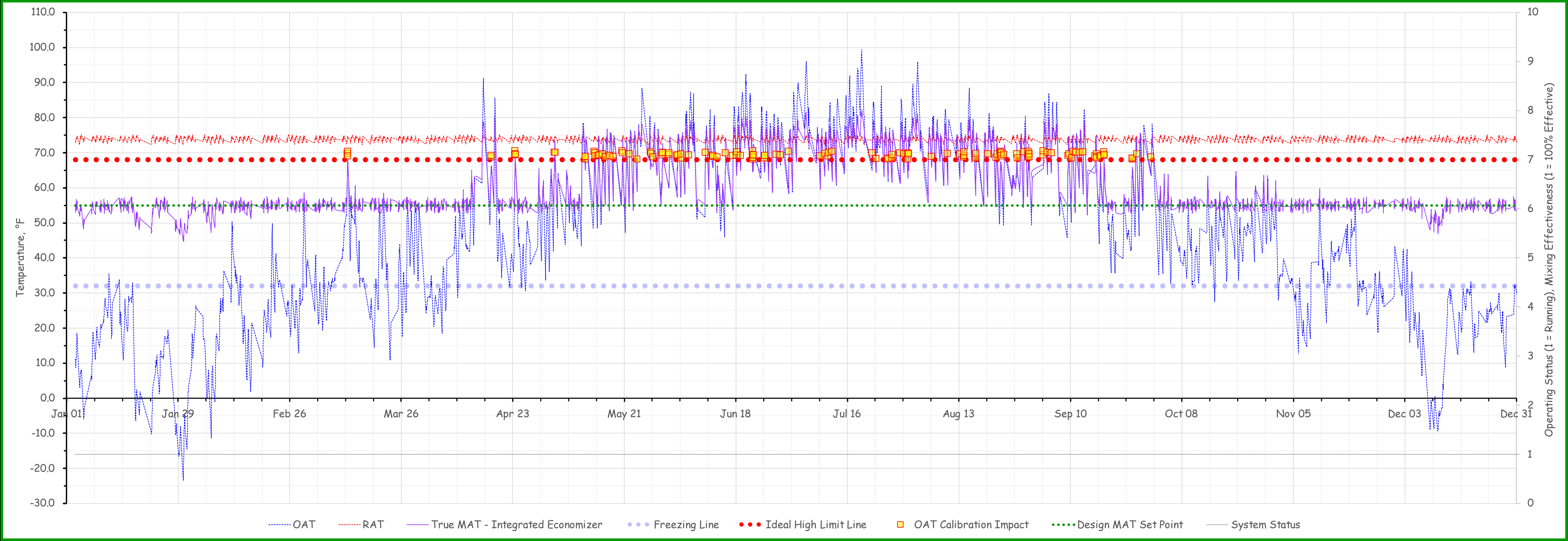


Its important to recognize that since outdoor air temperature is not what is controlled by the economizer, this error does not mean the economizer is not working properly in terms of mixing and transitions between operating modes; it probably is

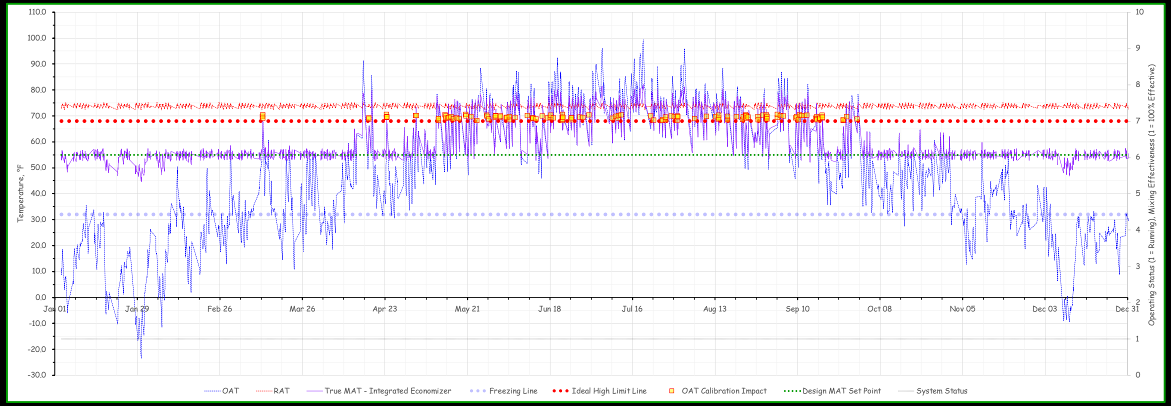



MAT vs. OAT
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
Mixing Effectiveness (100% is the maximum possible)
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated
OAT - Calibration Influenced Hi Limit
But it does impact the things *controlled* by outdoor air like the change-over to minimum outdoor air during hot, humid weather (note red squares with yellow fill)

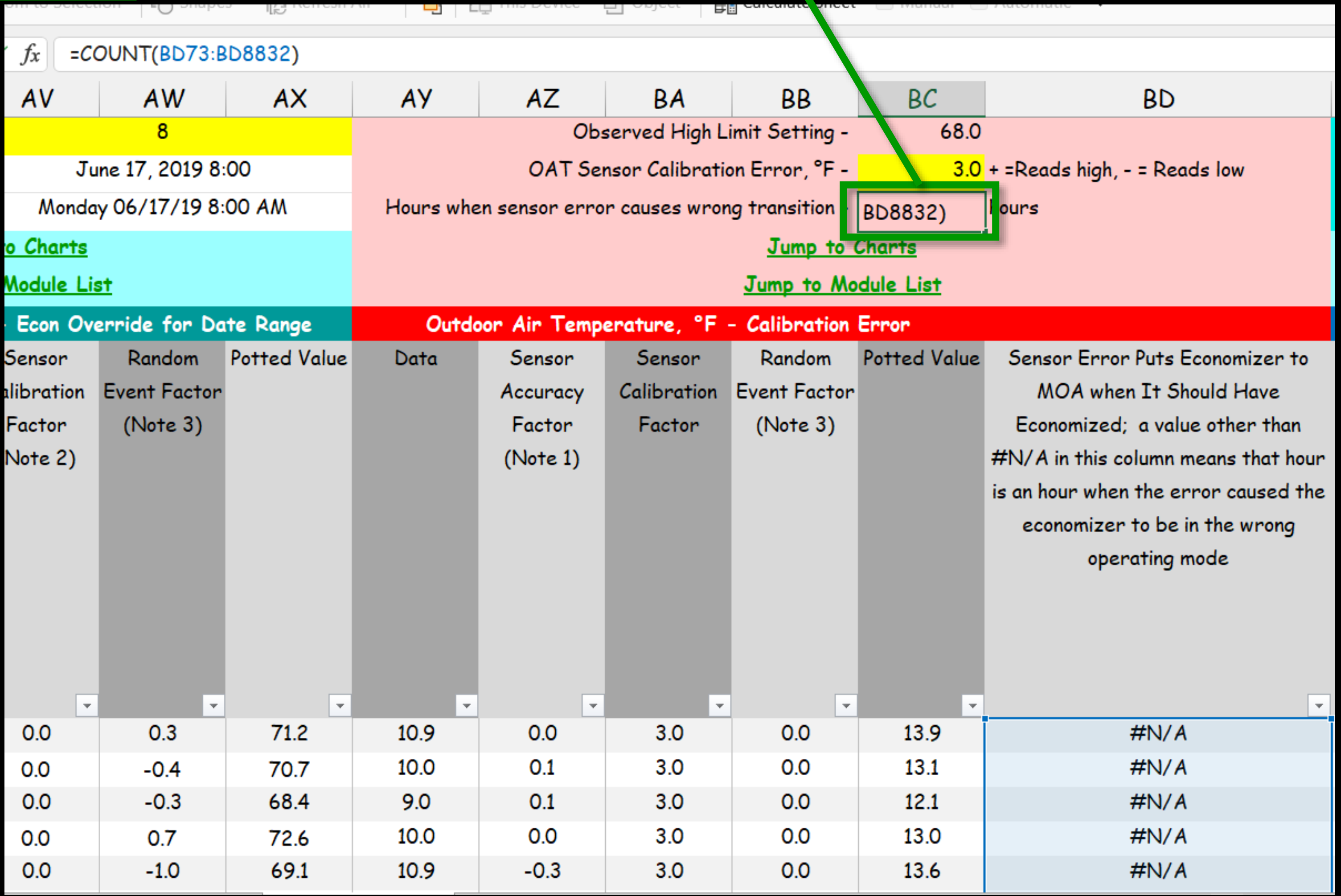
What's going on here?



The time series view may be helpful in cases like this since it shows when the issue is having an impact (note yellow squares with red outline)

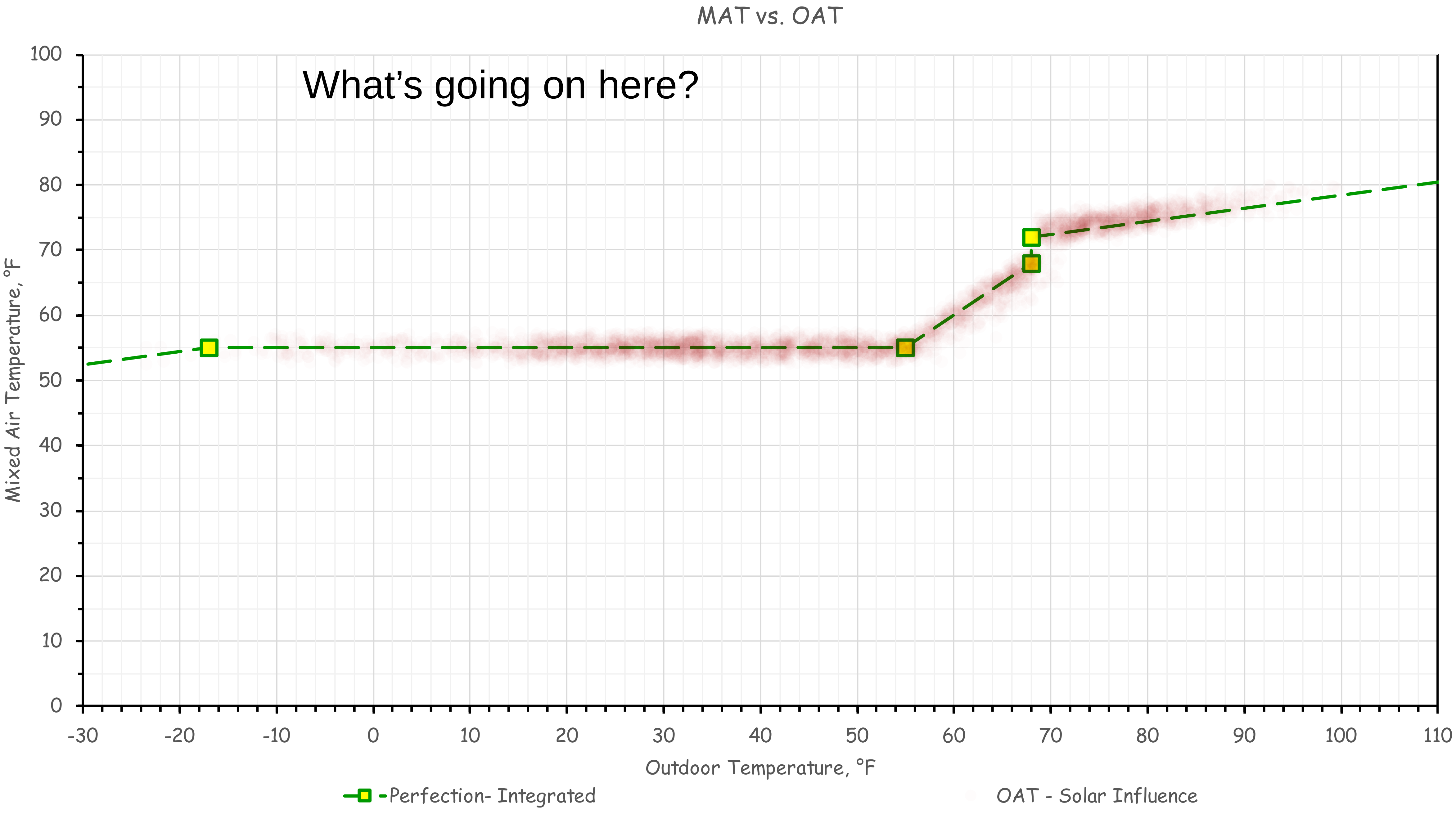


The formula in this cell is =COUNT(BD73:BD8832) which increments by 1 if the value in BD is a number

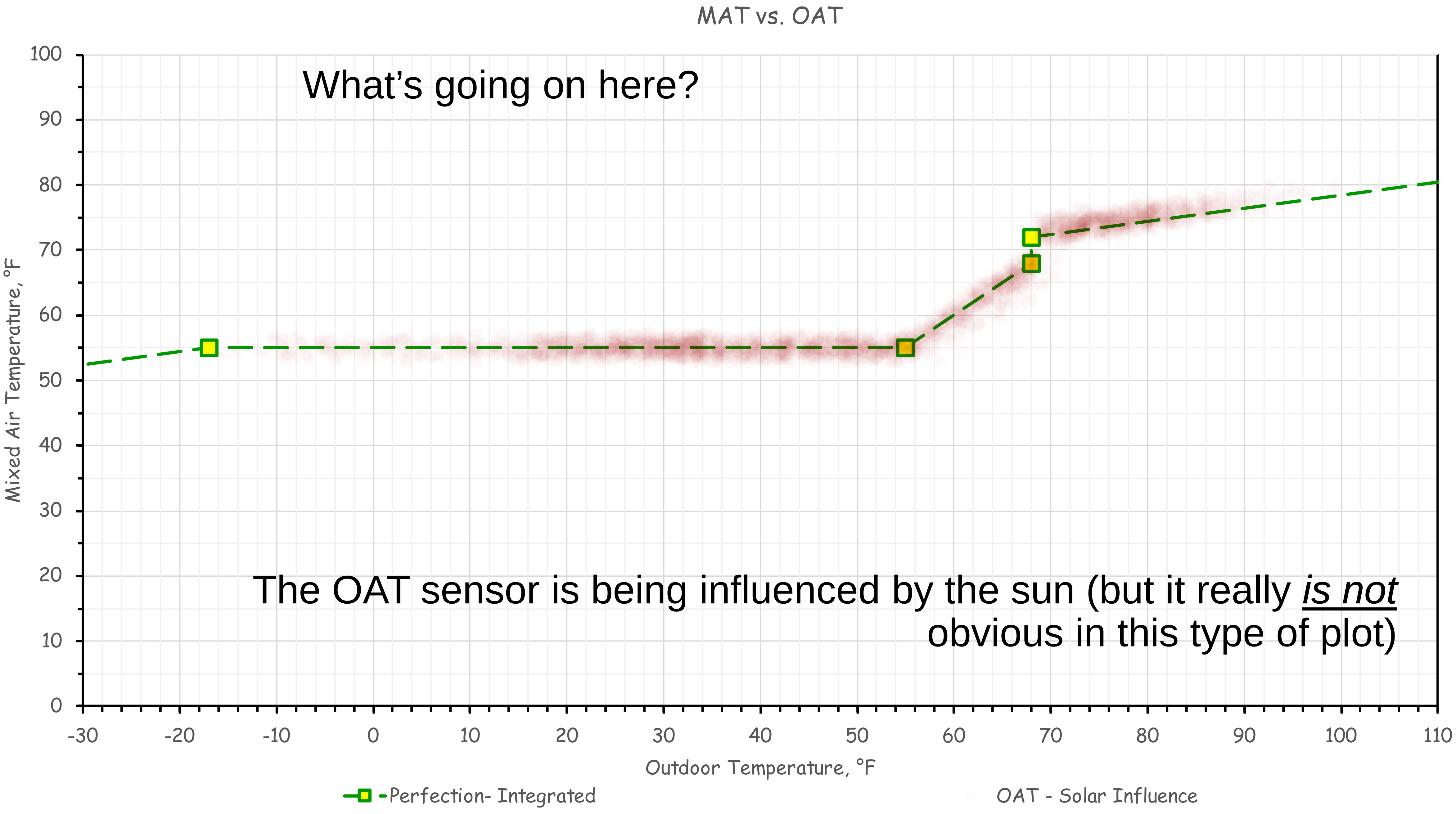


AV	AW	AX	AY	AZ	BA	BB	BC	BD
Sensor Calibration Factor (Note 2)	Random Event Factor (Note 3)	Potted Value	Data	Sensor Accuracy Factor (Note 1)	Sensor Calibration Factor	Random Event Factor (Note 3)	Potted Value	Sensor Error Puts Economizer to MOA when It Should Have Economized; a value other than #N/A in this column means that hour is an hour when the error caused the economizer to be in the wrong operating mode
0.0	0.3	71.2	10.9	0.0	3.0	0.0	13.9	#N/A
0.0	-0.4	70.7	10.0	0.1	3.0	0.0	13.1	#N/A
0.0	-0.3	68.4	9.0	0.1	3.0	0.0	12.1	#N/A
0.0	0.7	72.6	10.0	0.0	3.0	0.0	13.0	#N/A
0.0	-1.0	69.1	10.9	-0.3	3.0	0.0	13.6	#N/A

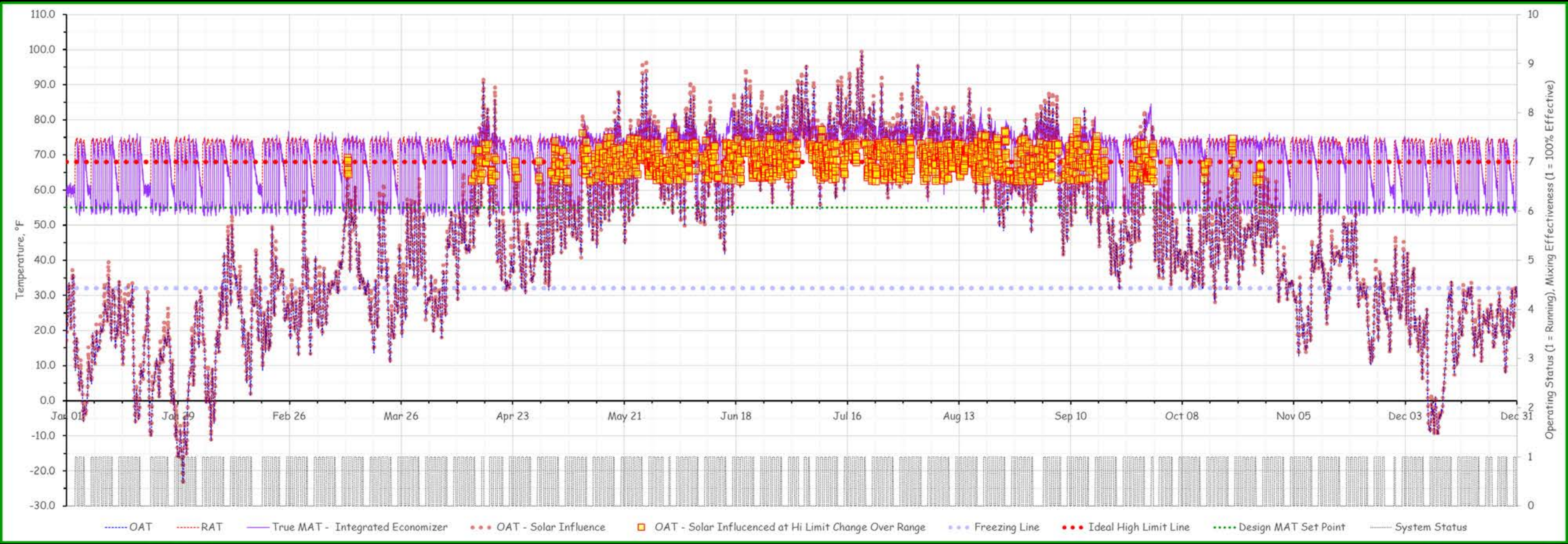
Using spreadsheet functions like =COUNT() can further quantify the issue and opportunity



MAT vs. OAT
What's going on here?
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
Perfection- Integrated
OAT - Solar Influence

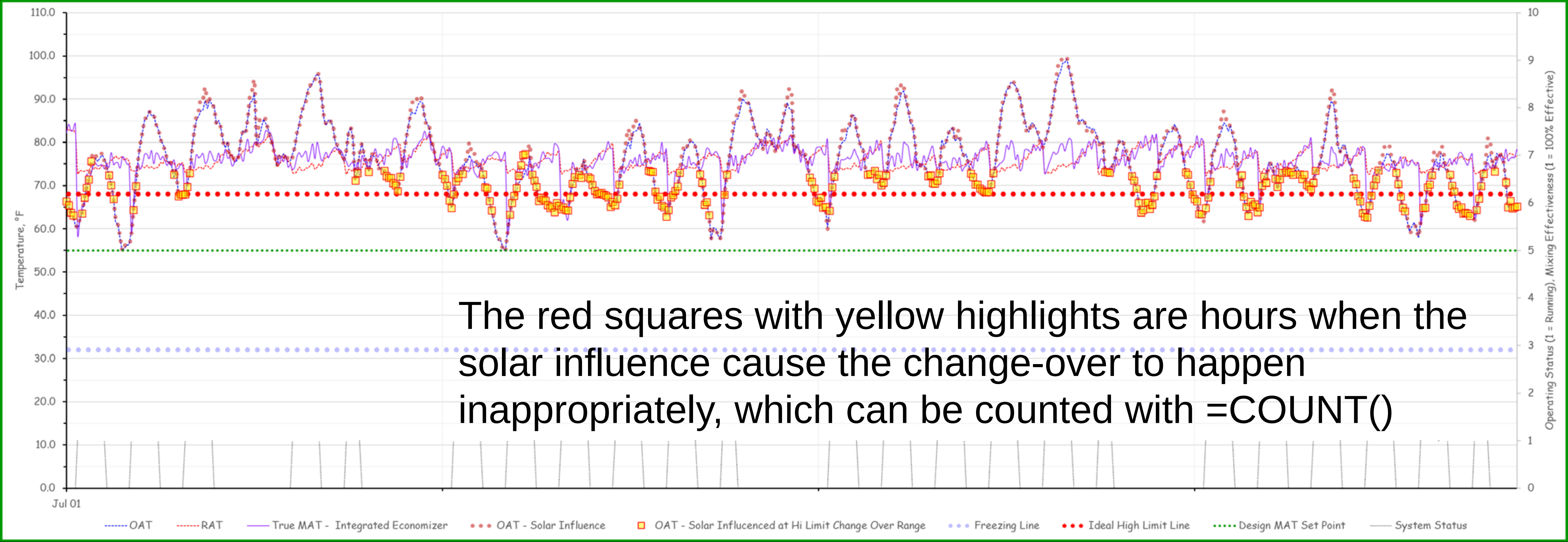


MAT vs. OAT
What's going on here?
The OAT sensor is being influenced by the sun (but it really *is not* obvious in this type of plot)
Mixed Air Temperature, °F
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
OAT - Solar Influence



The time series view provides more insight on this type of fault, especially if you create a series to highlight the issue

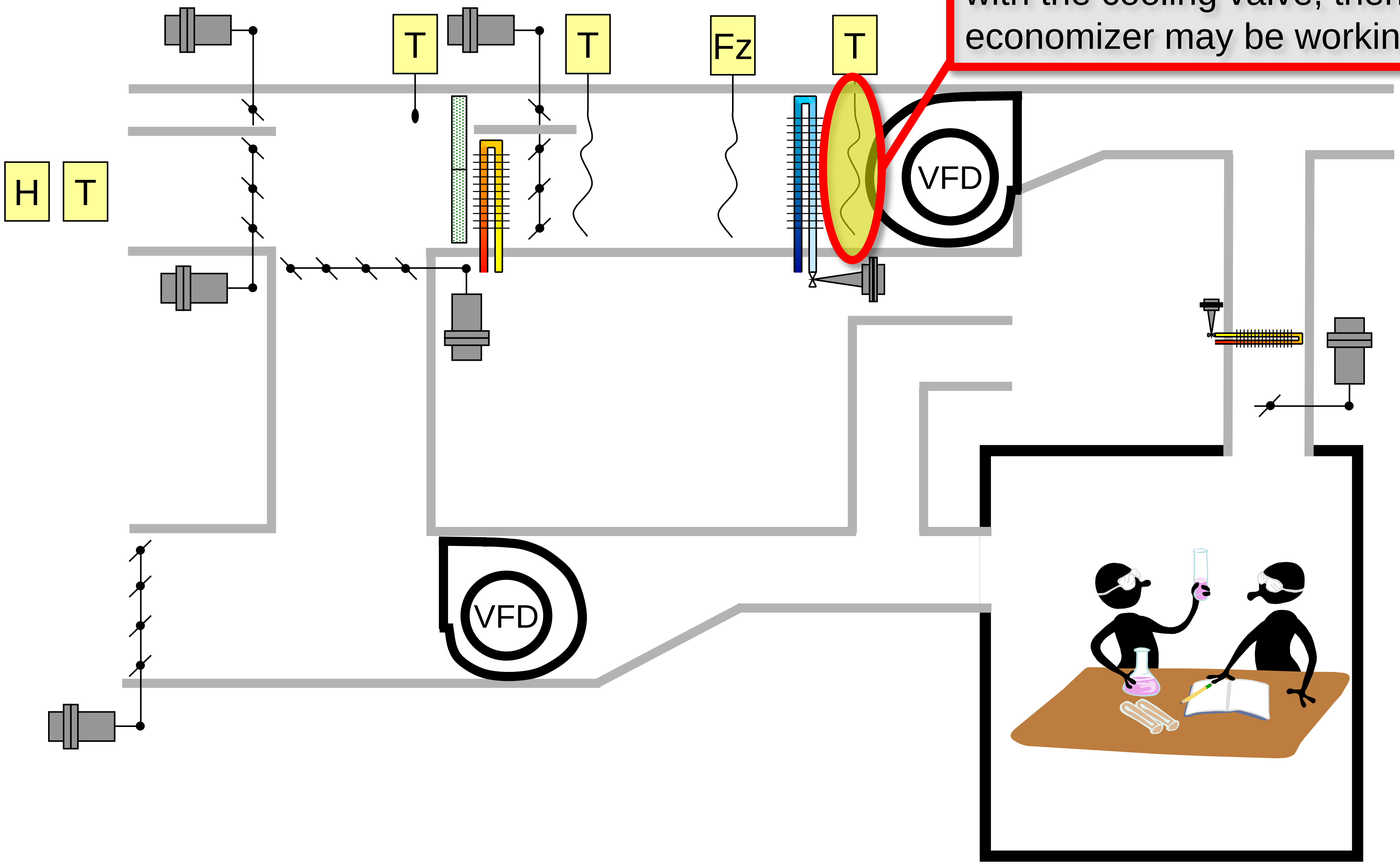
The red dot series is the solar influenced OAT; the solid blue line is reality

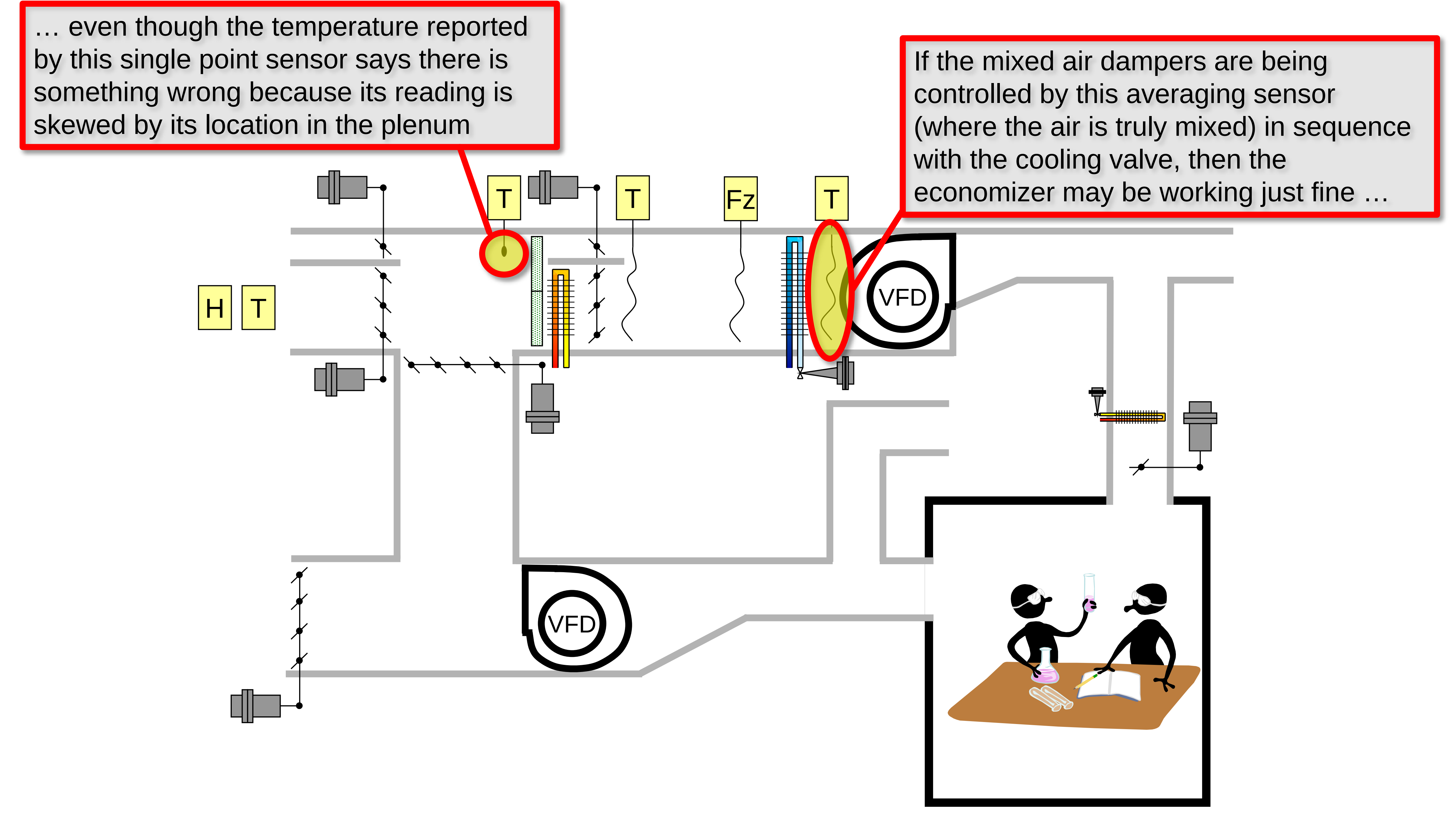


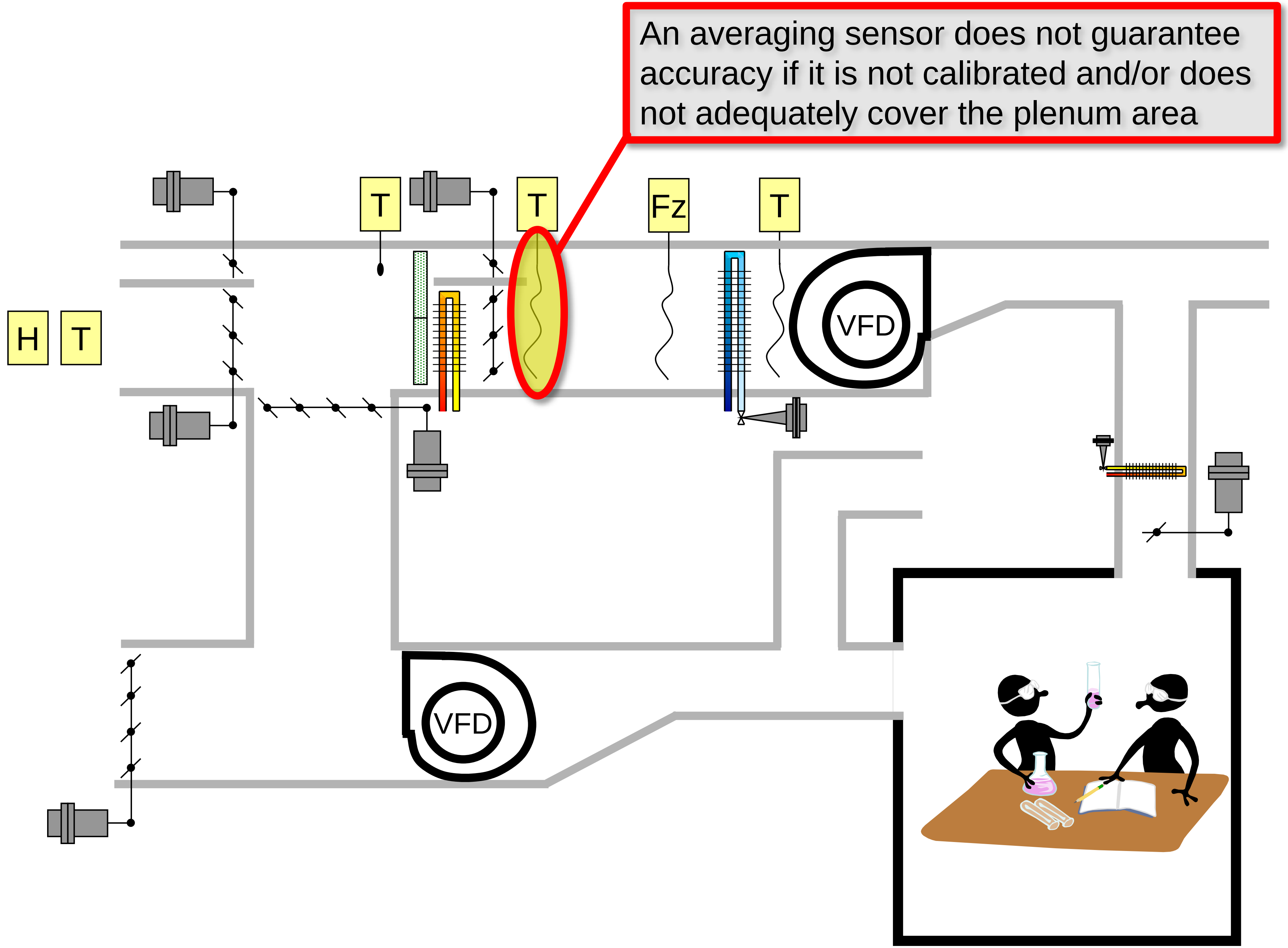
The red squares with yellow highlights are hours when the solar influence cause the change-over to happen inappropriately, which can be counted with =COUNT()

The time series view provides more insight on this type of fault, especially if you create a series to highlight the issue

If the mixed air dampers are being controlled by this averaging sensor (where the air is truly mixed) in sequence with the cooling valve, then the economizer may be working just fine …




… even though the temperature reported by this single point sensor says there is something wrong because its reading is skewed by its location in the plenum
If the mixed air dampers are being controlled by this averaging sensor (where the air is truly mixed) in sequence with the cooling valve, then the economizer may be working just fine …
H
T
T
T
Fz
T
VFD
VFD



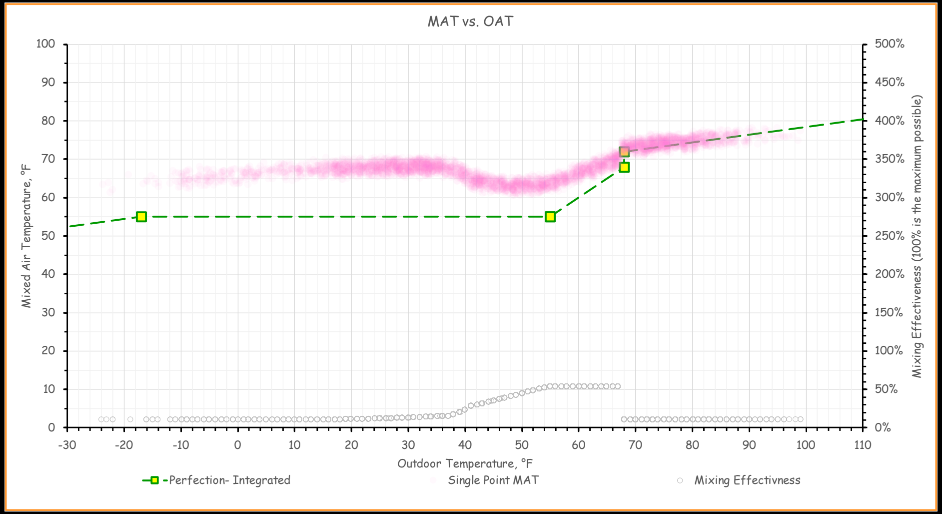
An averaging sensor does not guarantee accuracy if it is not calibrated and/or does not adequately cover the plenum area
H
T
T
T
Fz
T
VFD
VFD

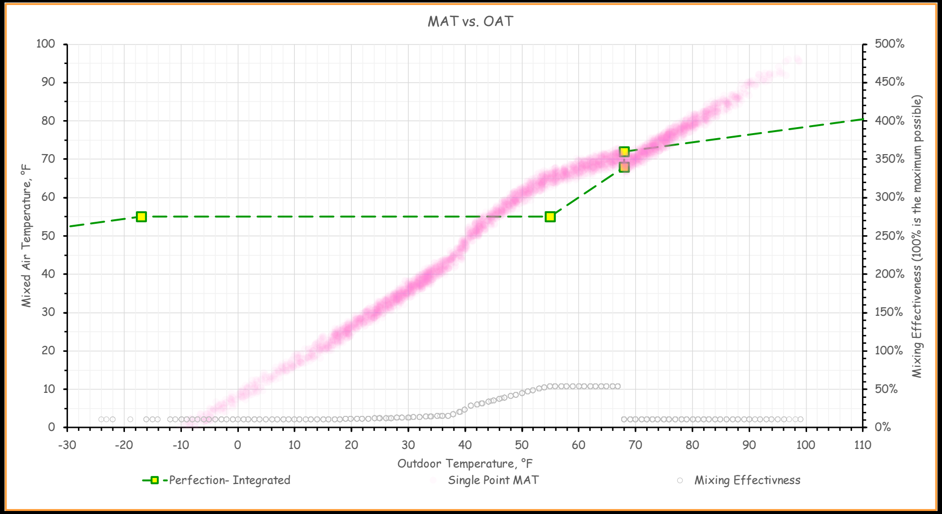
Mixed Air Sensor Bottom Lines

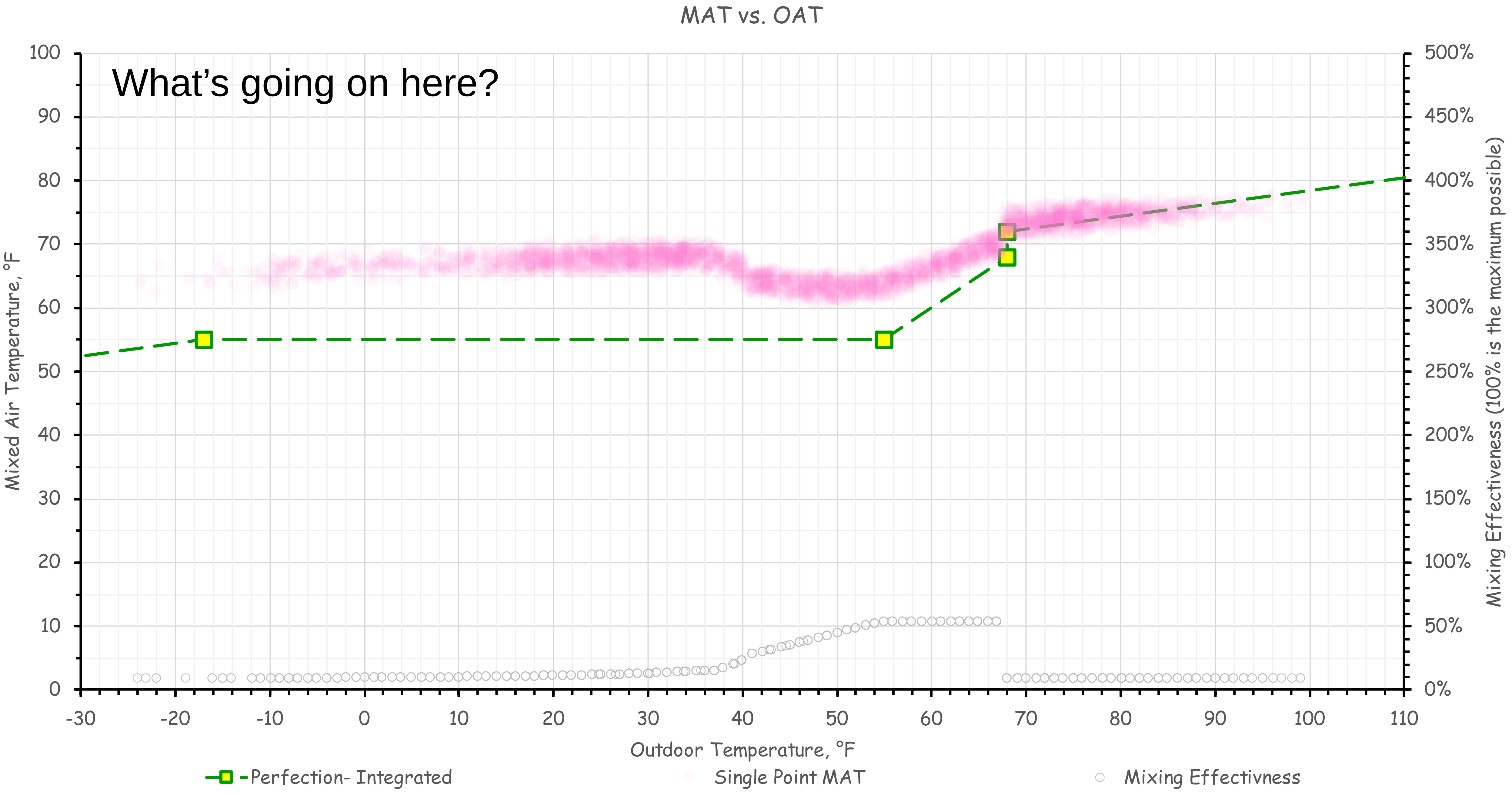
The patterns in the resulting data clouds may not be immediately obvious until:

- You have been exposed to them
- You have had a chance to think about them

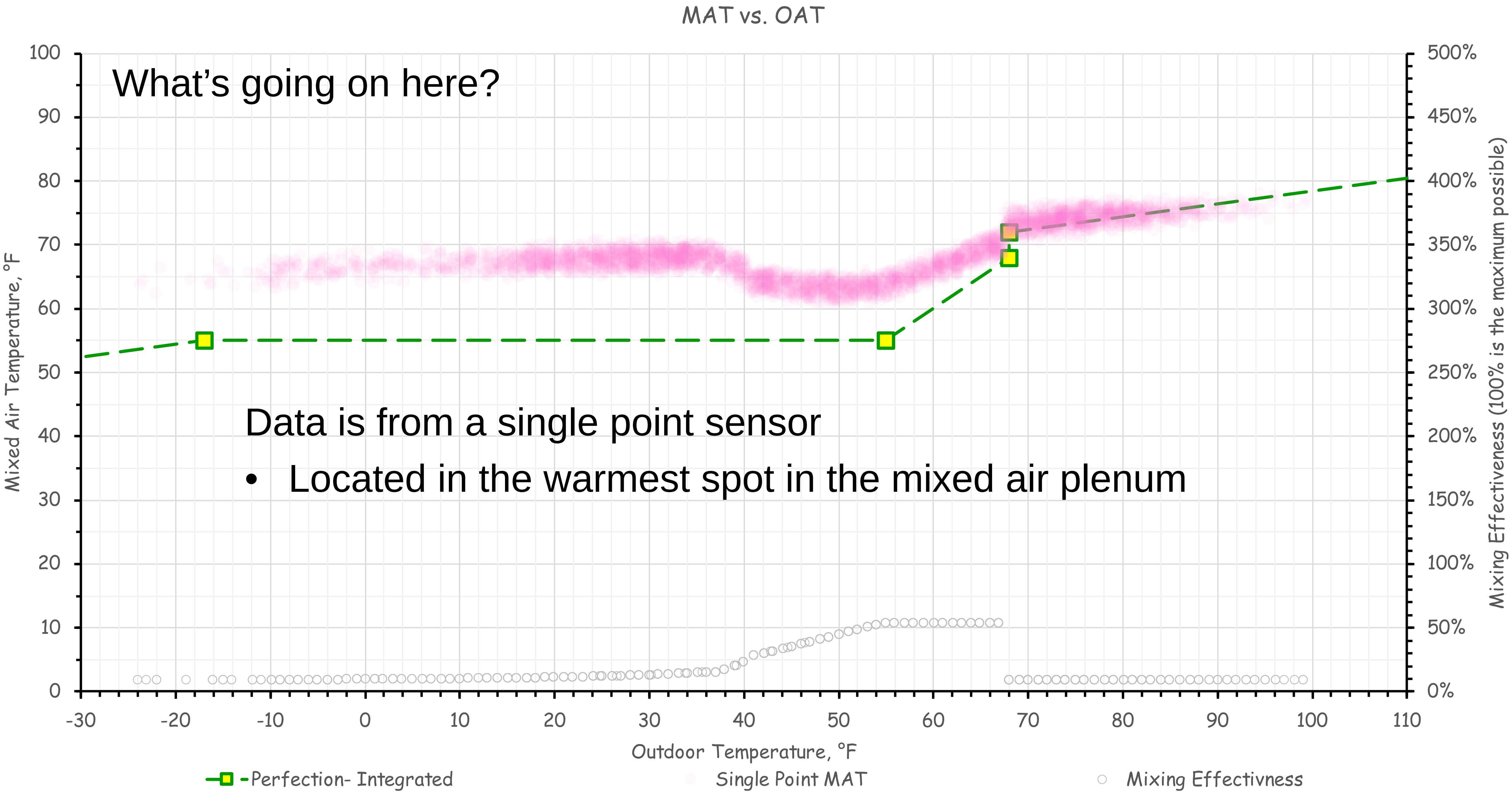
Thus, this, the tool behind this presentation and the presentation itself



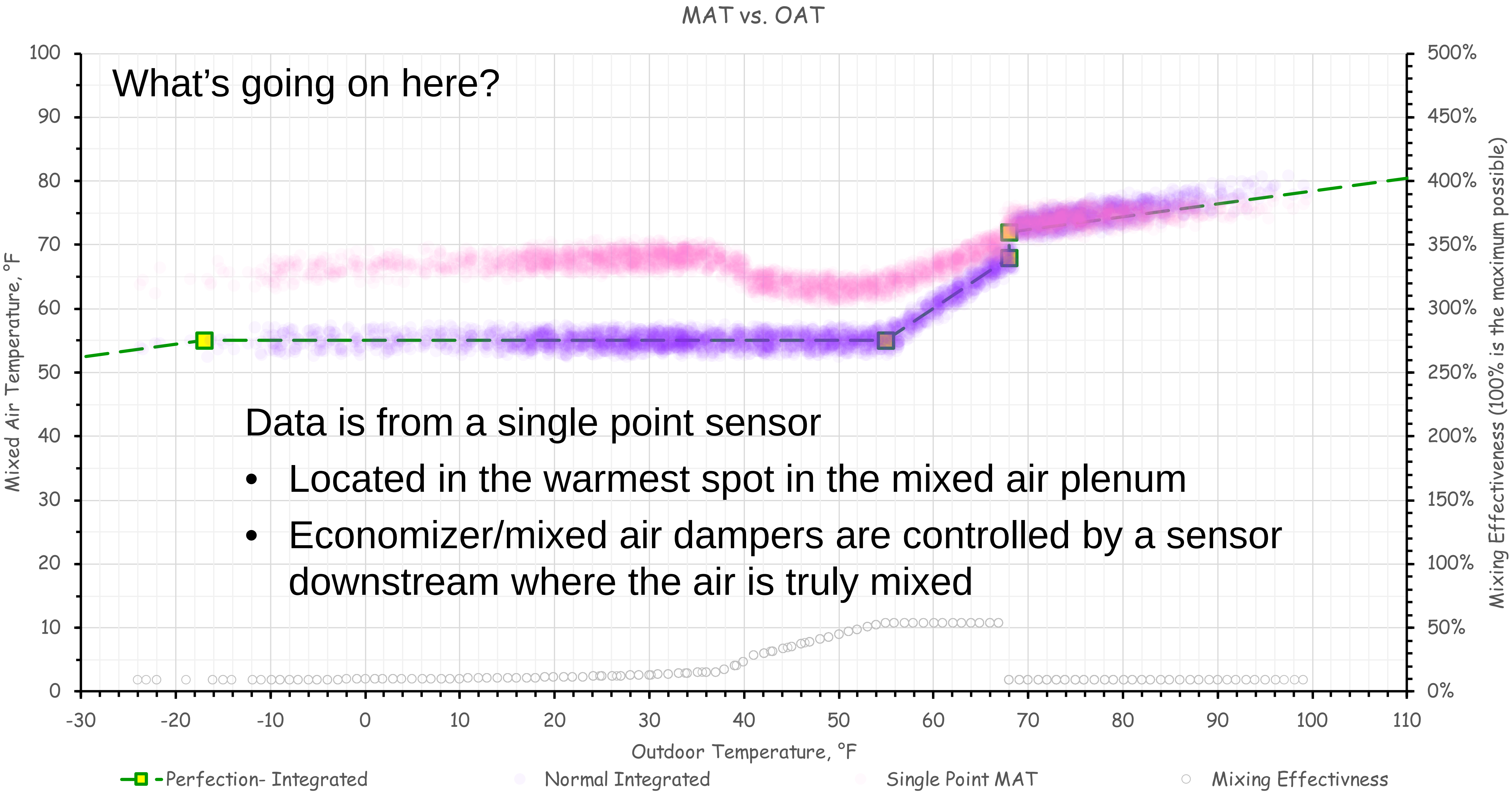




MAT vs. OAT
What’s going on here?
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Single Point MAT
Mixing Effectivness

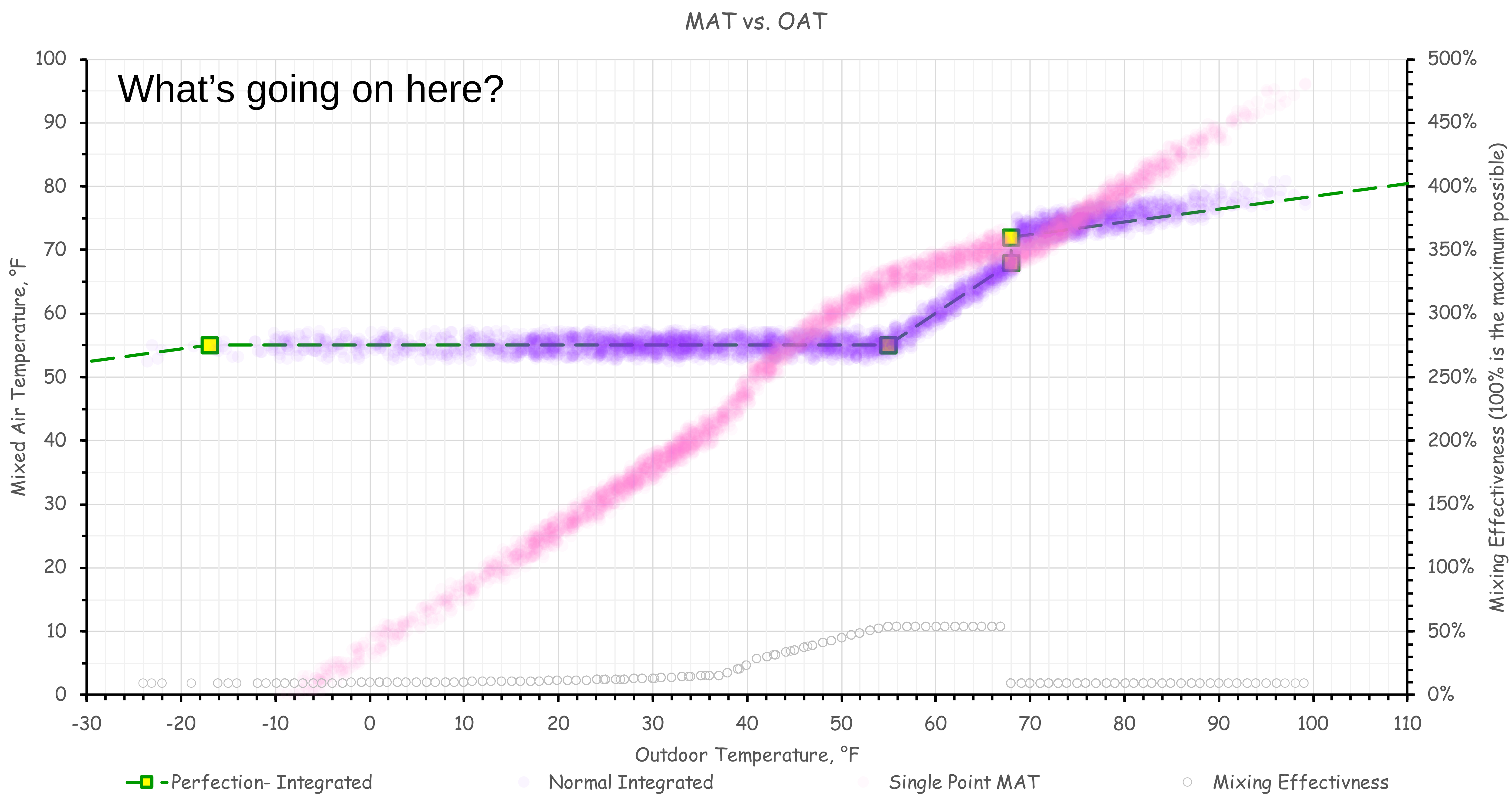

MAT vs. OAT
What’s going on here?
Data is from a single point sensor
• Located in the warmest spot in the mixed air plenum
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Single Point MAT
Mixing Effectivness

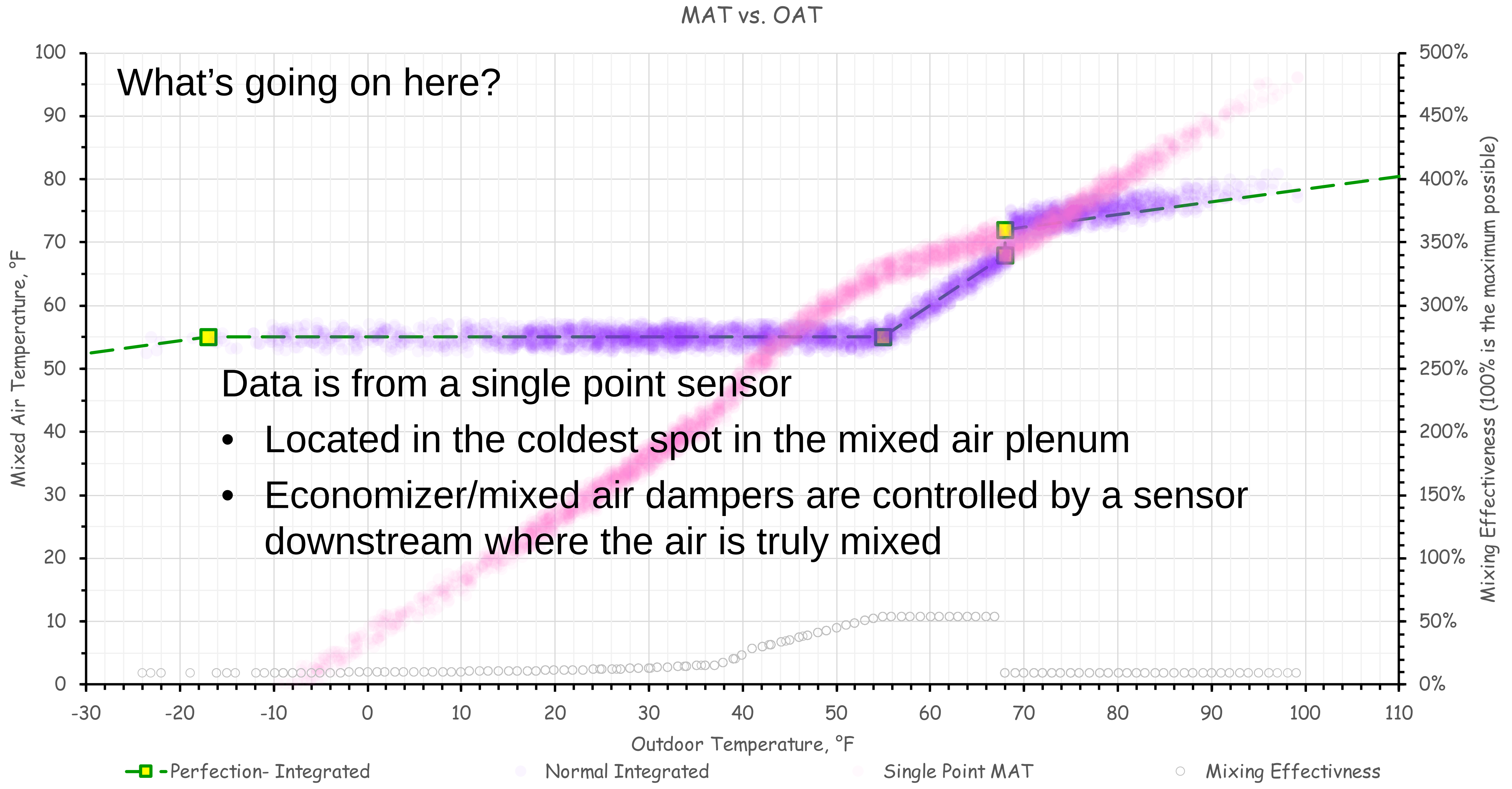
What’s going on here?



Data is from a single point sensor

- Located in the warmest spot in the mixed air plenum
- Economizer/mixed air dampers are controlled by a sensor downstream where the air is truly mixed

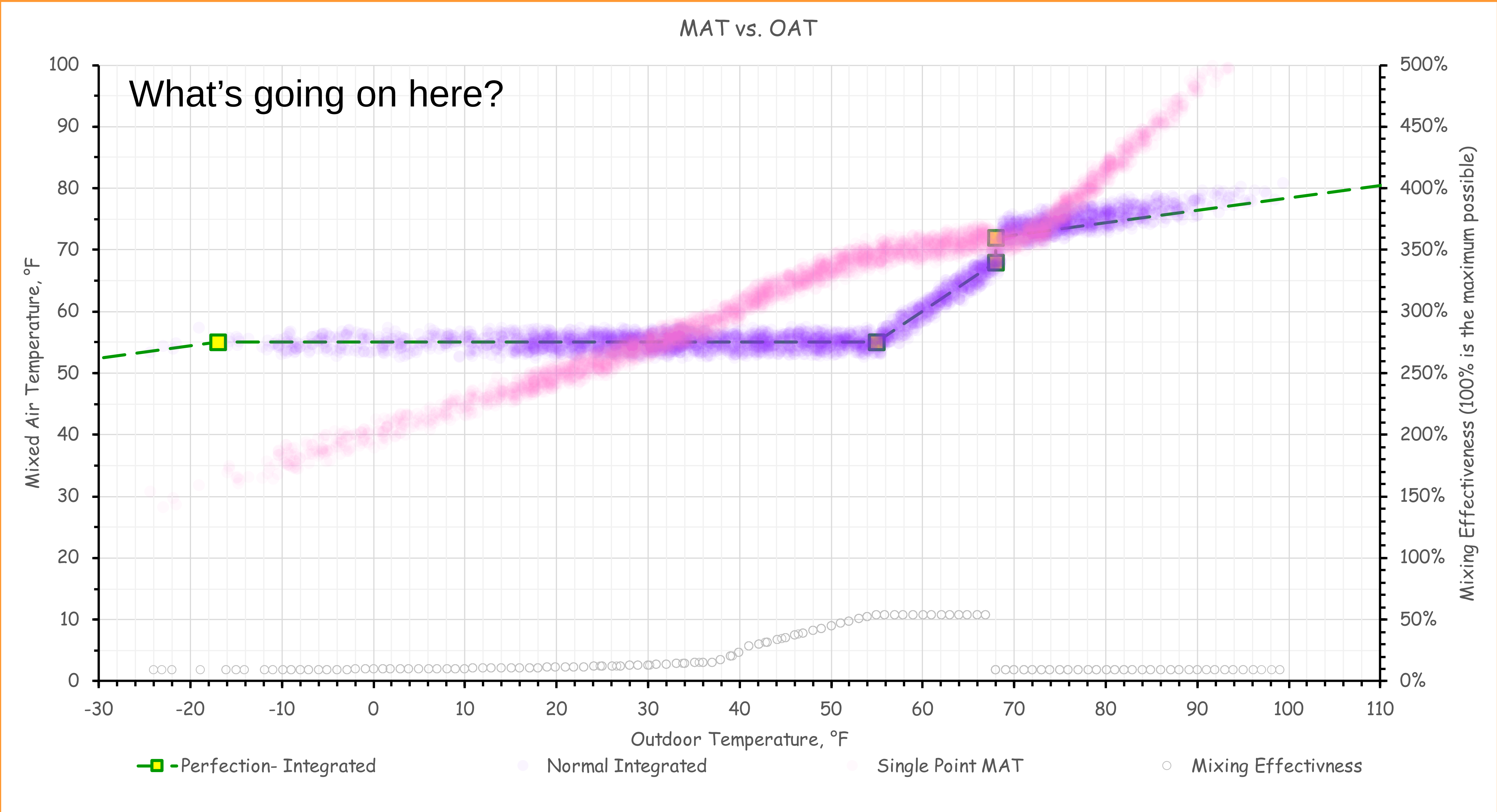

MAT vs. OAT
What’s going on here?
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
Perfection- Integrated
Normal Integrated
Single Point MAT
Mixing Effectivness
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110



What's going on here?

Data is from a single point sensor

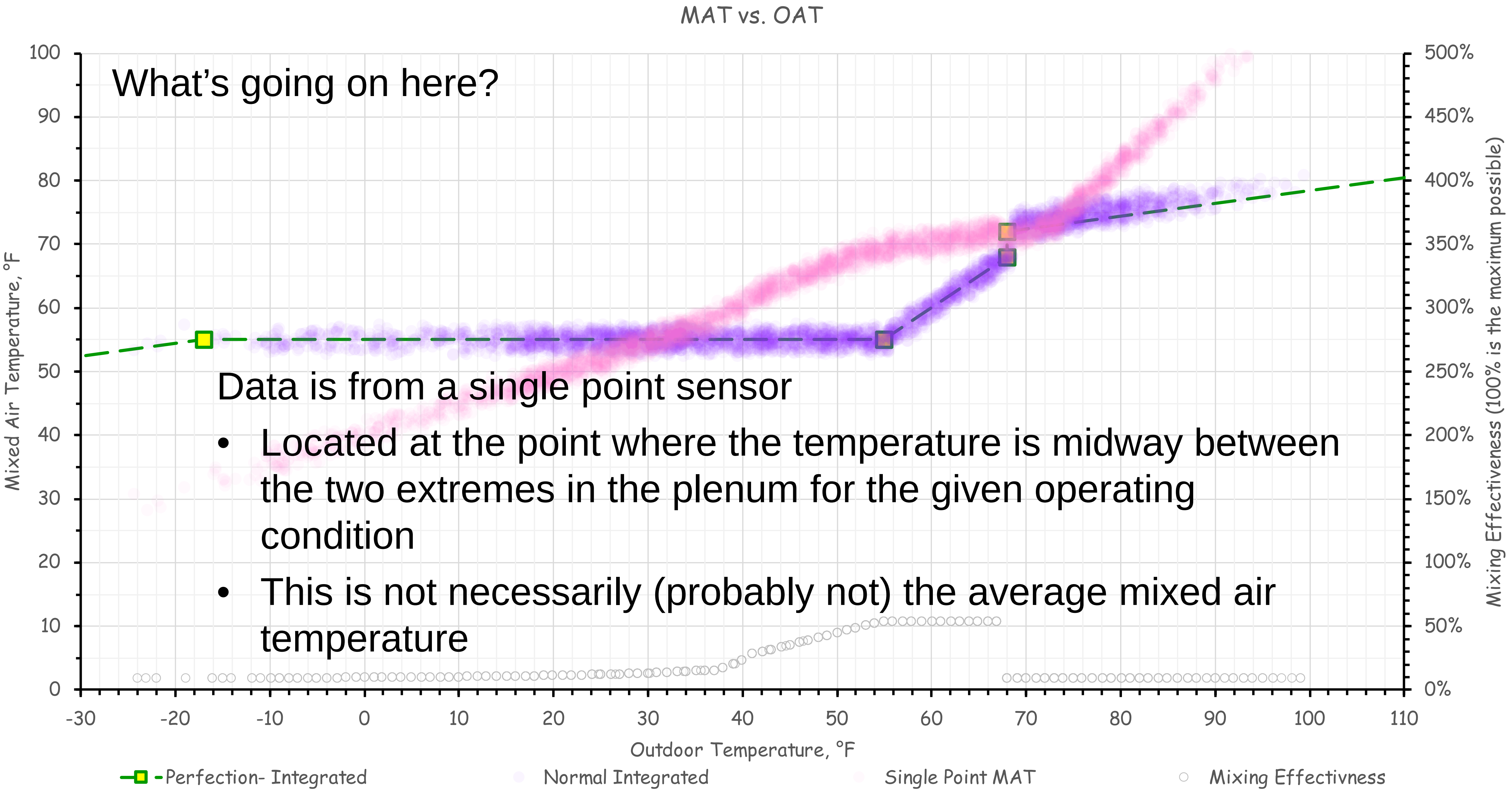
- Located in the coldest spot in the mixed air plenum
- Economizer/mixed air dampers are controlled by a sensor downstream where the air is truly mixed

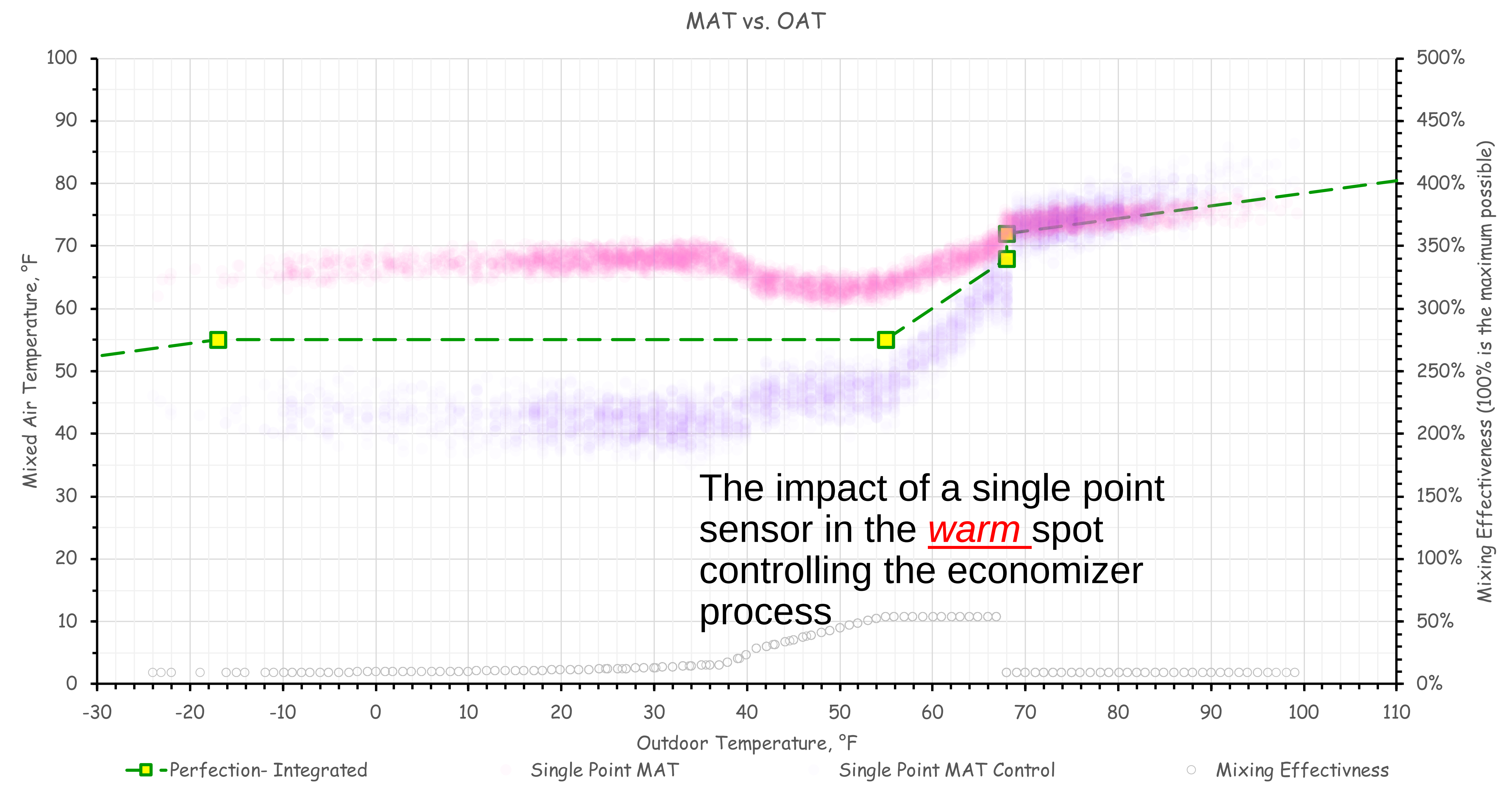

MAT vs. OAT
What's going on here?
Mixed Air Temperature, °F
Outdoor Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Perfection- Integrated
Normal Integrated
Single Point MAT
Mixing Effectivness

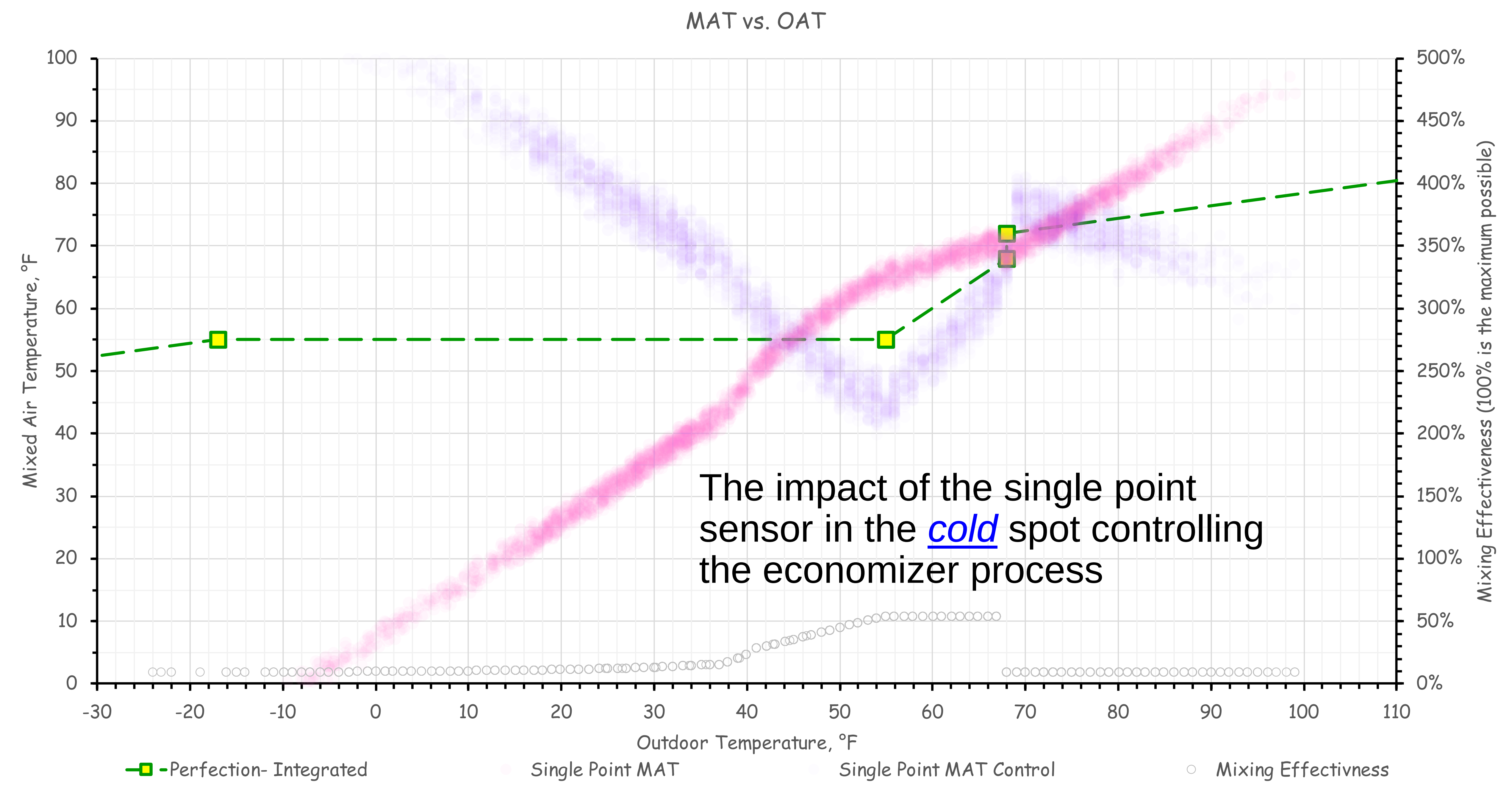
What's going on here?

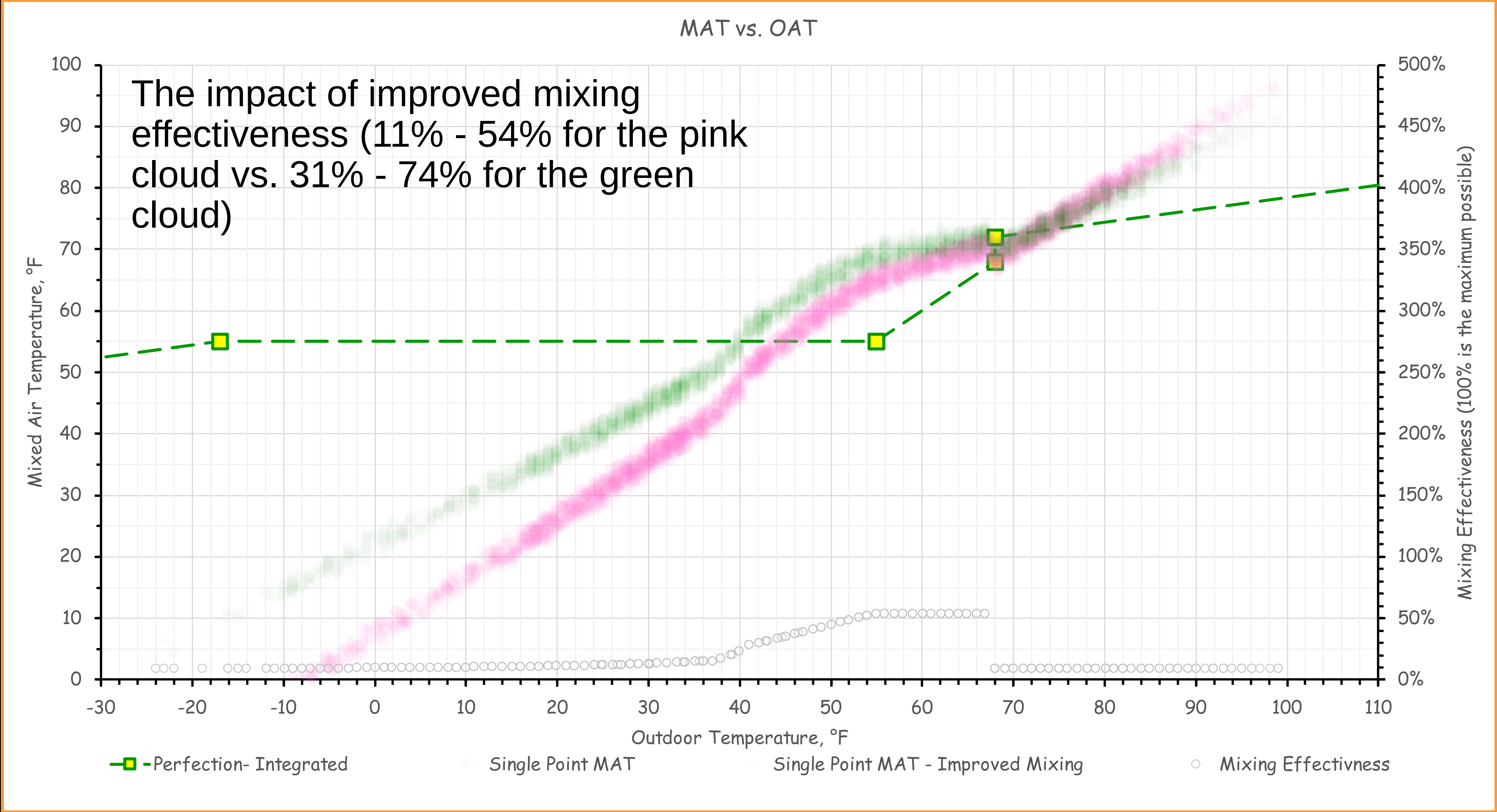
Data is from a single point sensor

- Located at the point where the temperature is midway between the two extremes in the plenum for the given operating condition
- This is not necessarily (probably not) the average mixed air temperature



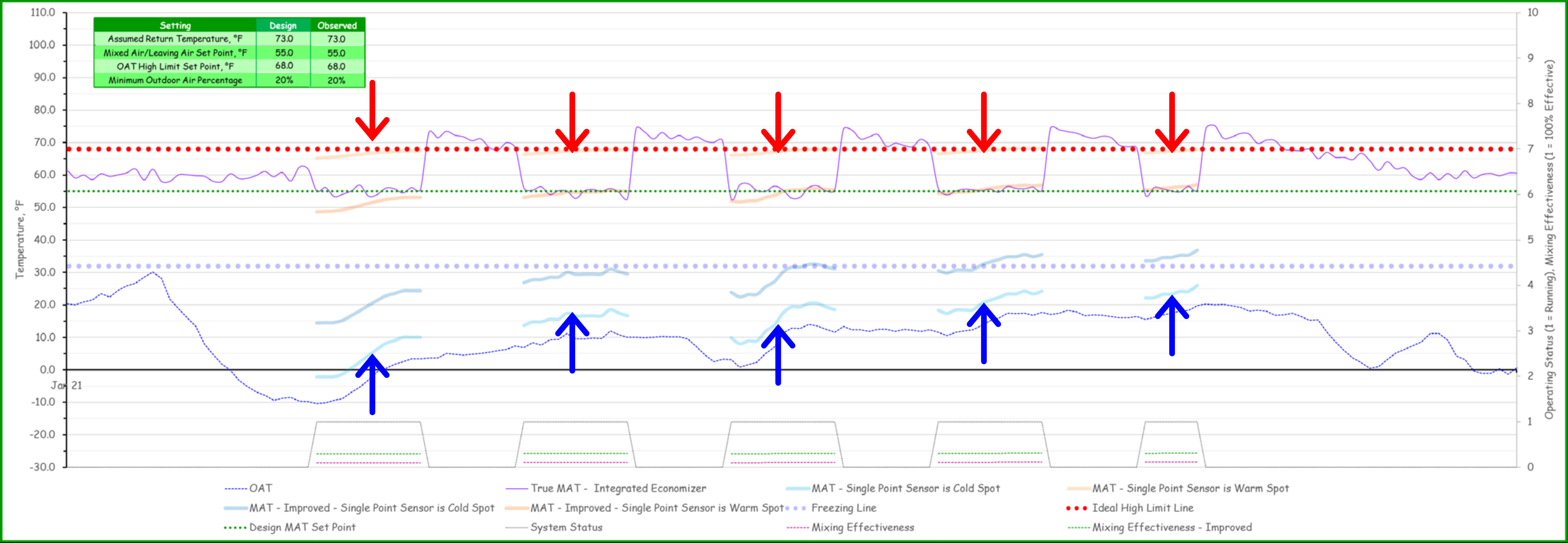

MAT vs. OAT
Mixed Air Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
Mixing Effectiveness (100% is the maximum possible)
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
Outdoor Temperature, °F
The impact of a single point sensor in the warm spot controlling the economizer process
Perfection- Integrated
Single Point MAT
Single Point MAT Control
Mixing Effectivness


MAT vs. OAT
Mixed Air Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
Outdoor Temperature, °F
100
90
80
70
60
50
40
30
20
10
0
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
The impact of the single point sensor in the cold spot controlling the economizer process
Perfection- Integrated
Single Point MAT
Single Point MAT Control
Mixing Effectivness

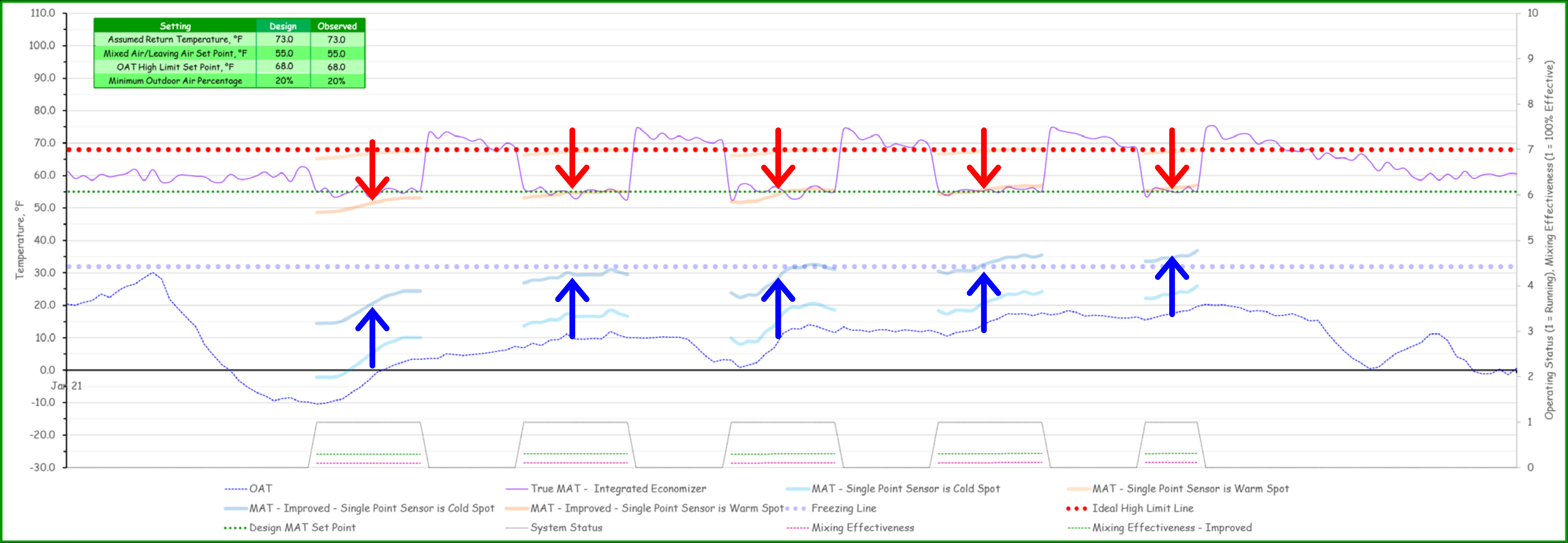


MAT vs. OAT
The impact of improved mixing effectiveness (11% - 54% for the pink cloud vs. 31% - 74% for the green cloud)
Mixed Air Temperature, °F
Outdoor Temperature, °F
Mixing Effectiveness (100% is the maximum possible)
100
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
Perfection- Integrated
Single Point MAT
Single Point MAT - Improved Mixing
Mixing Effectivness

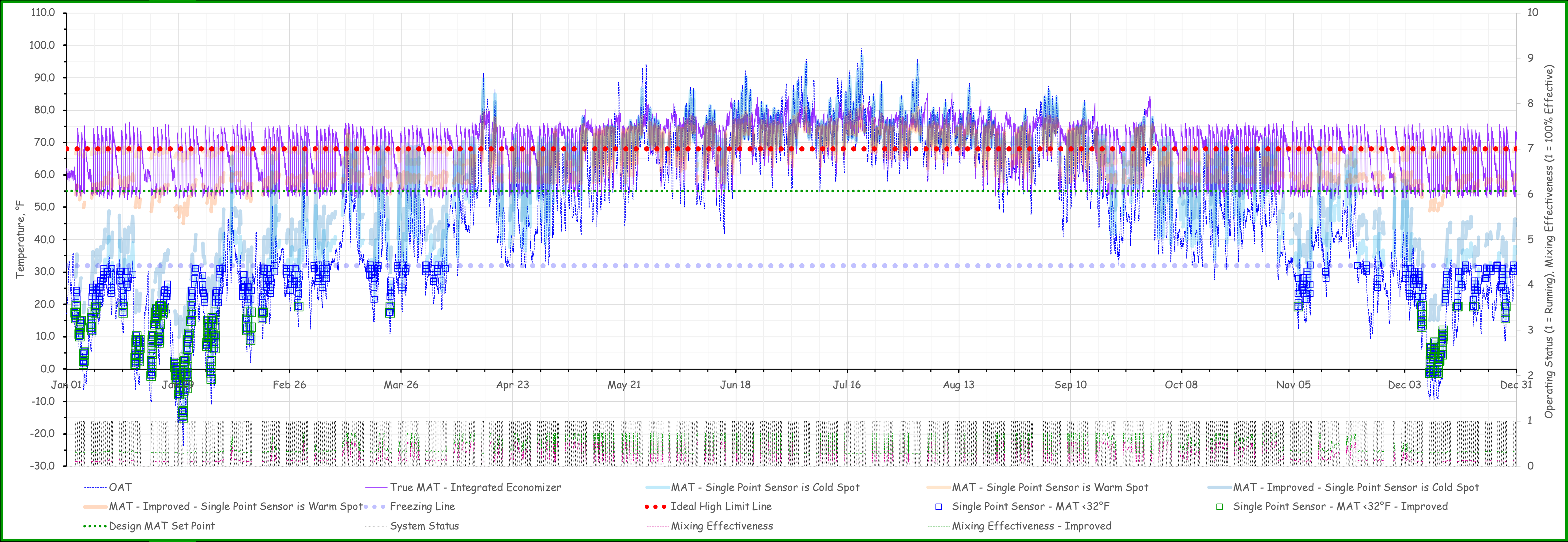
Highlighting Improved Mixing



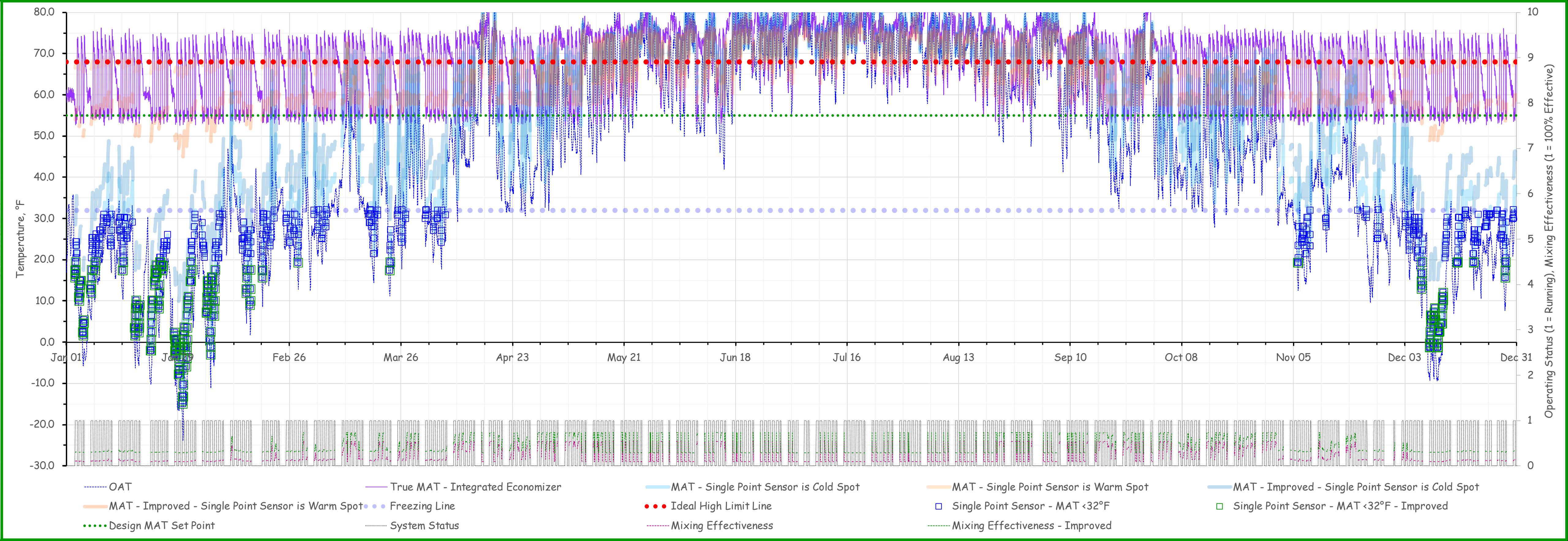
Highlighting Improved Mixing



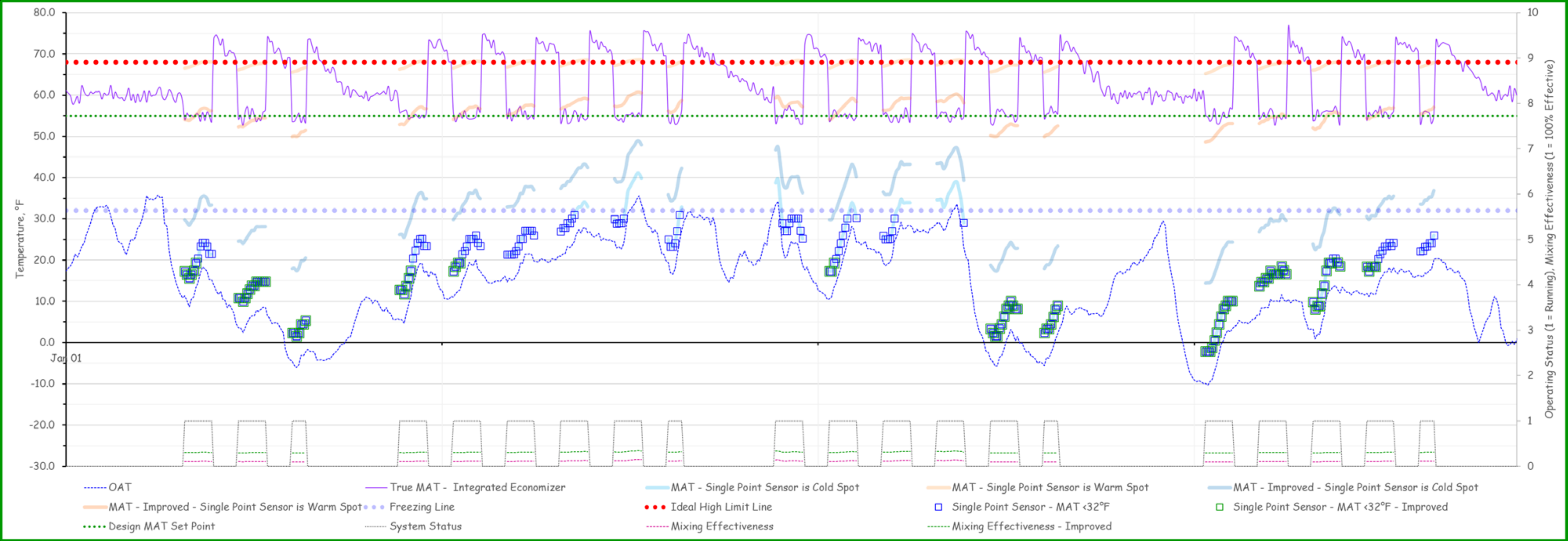
Fewer Sub-freezing Plenum Conditions



Fewer Sub-freezing Plenum Conditions



Fewer Sub-freezing Plenum Conditions



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