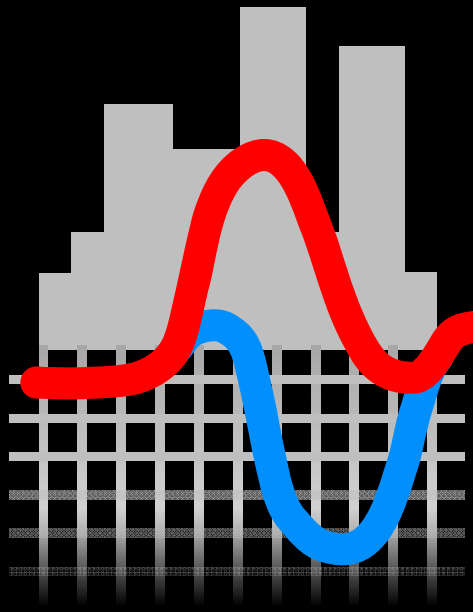


Facility Dynamics
ENGINEERING

Controlling the Mixed Air Section

Assessing an Economizer (Supplemental)

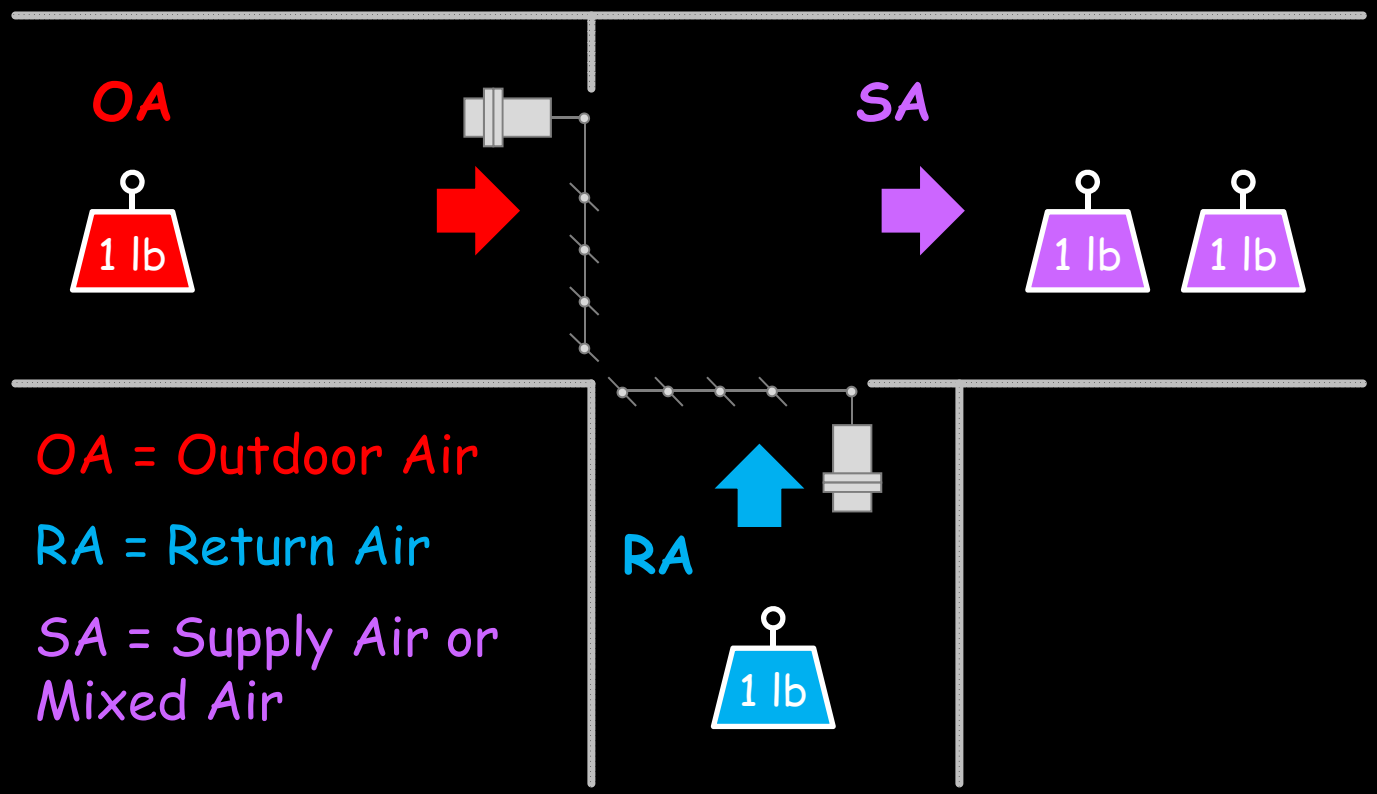
Presented By:

David Sellers; Facility Dynamics Engineering

Senior Engineer

NAVFAC, San Diego

Conservation of Mass in a Mixed Air Plenum



Conservation of Mass in a Mixed Air Plenum

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

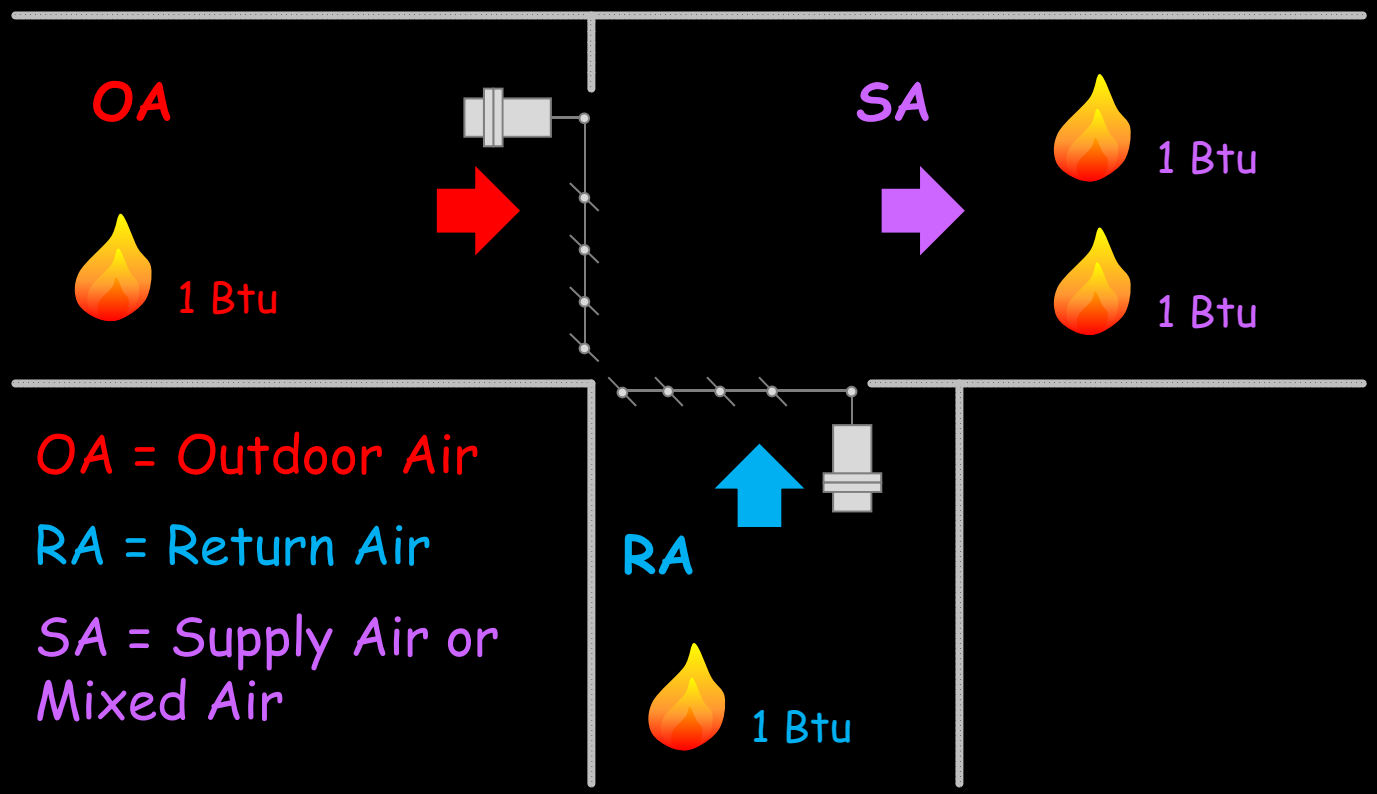
Where:

$\dot{m}_{OutdoorAir}$ = 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



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

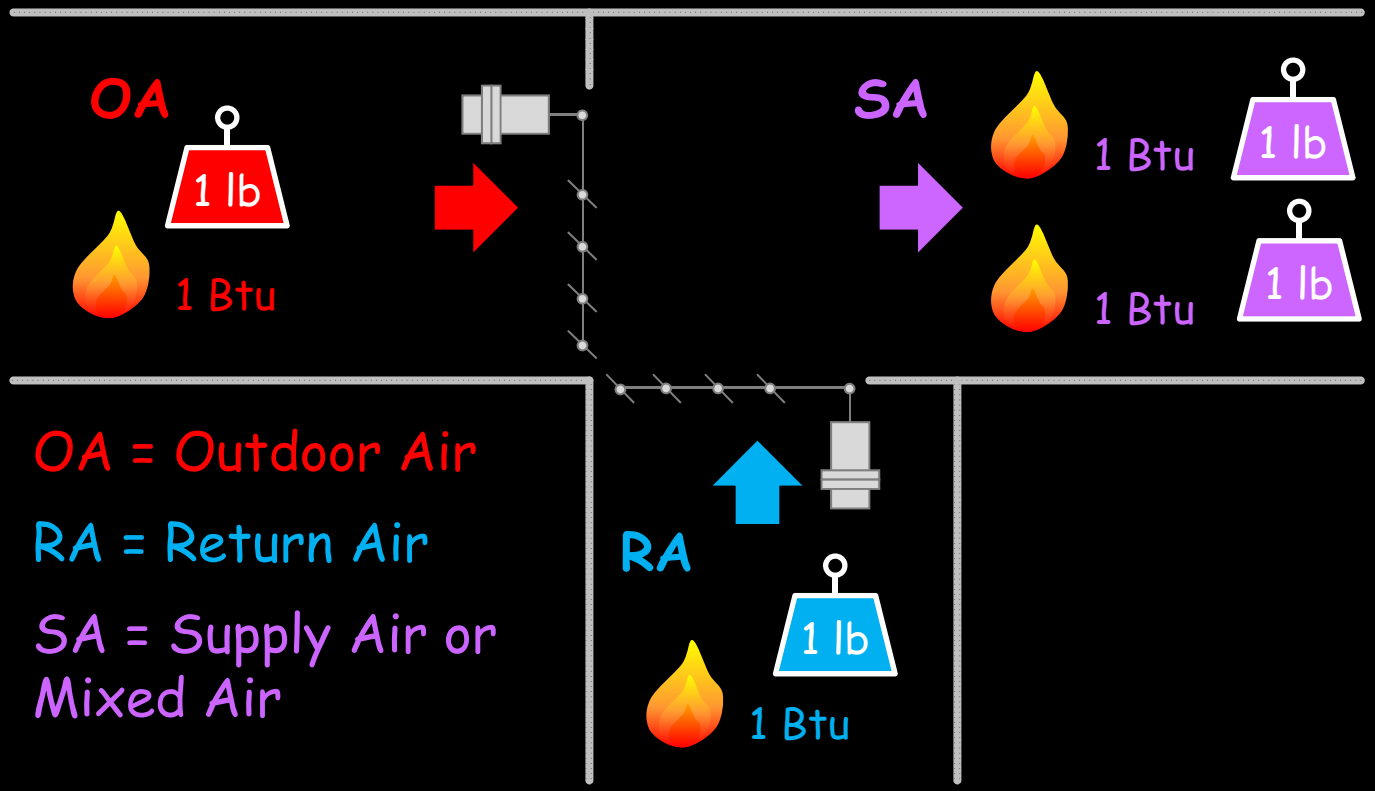
J = Mechanical equivalent of heat; 778 ft-lb/Btu

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



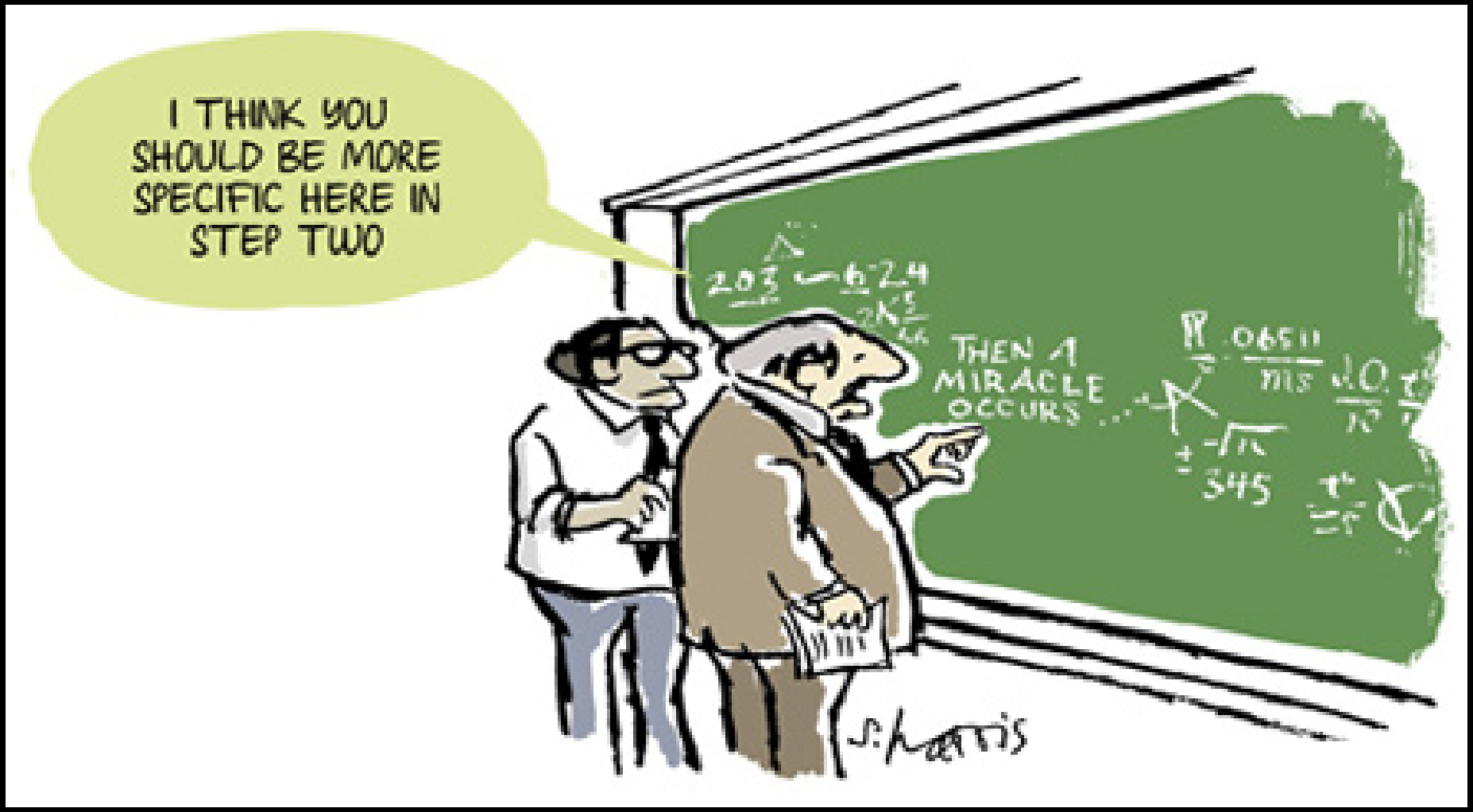
Conservation of Mass and Energy in a Mixed Air Plenum

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

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 [Economizers – The Physics of a Mixed Air Plenum]() at [www.Av8rDAS.Wordpress.com]() for the in-between steps

A Few Other Useful Relationships

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

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

A Few Other Useful Relationships

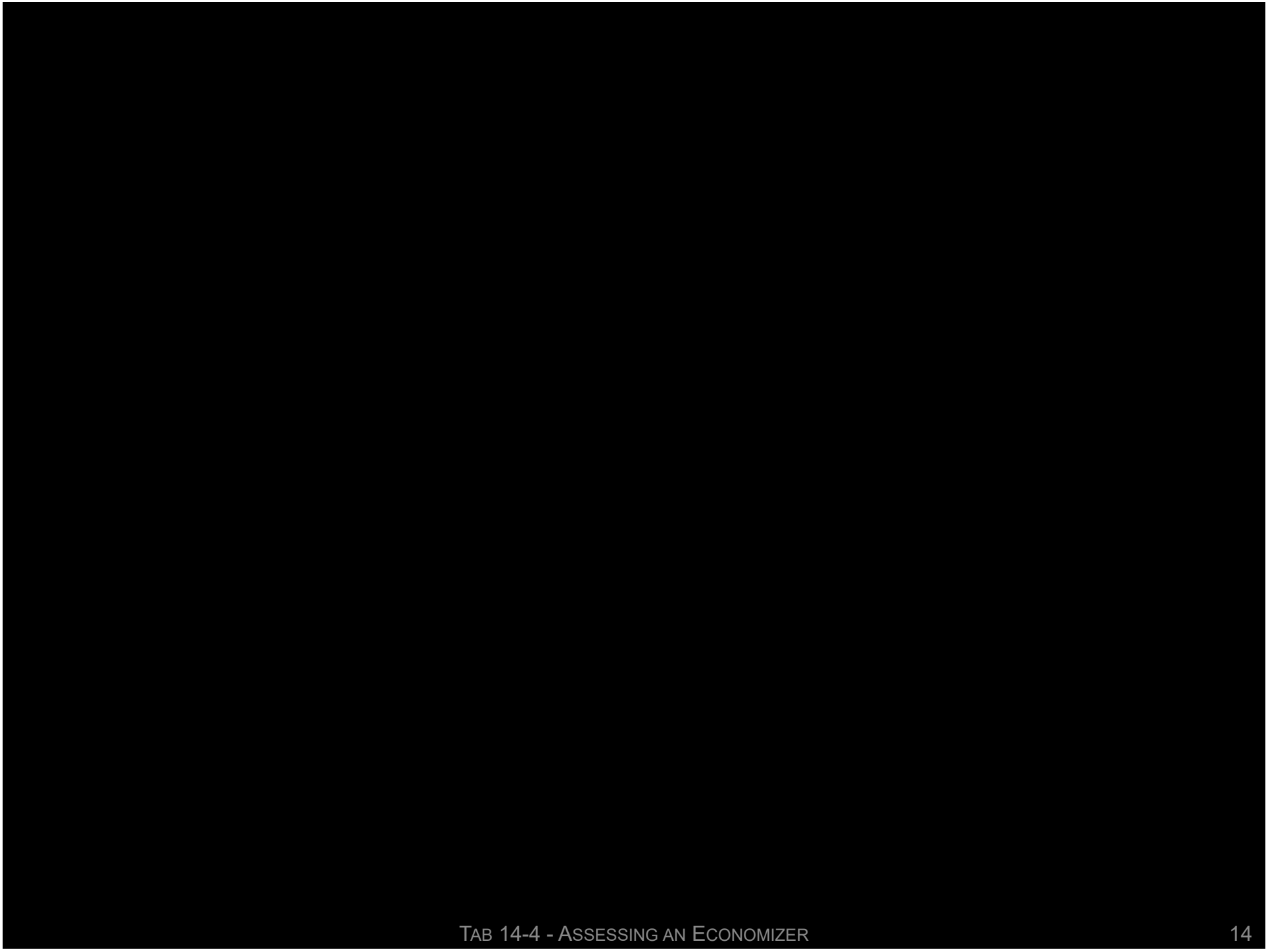
$$t_{OutdoorAir} = \left[\frac{\left(t_{MixedAir_{Design}} - t_{ReturnAir} \right)}{\%_{OutdoorAir}} \right] + t_{ReturnAir}$$

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.

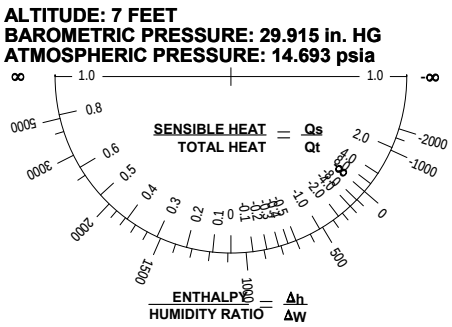
A Few Other Useful Relationships

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

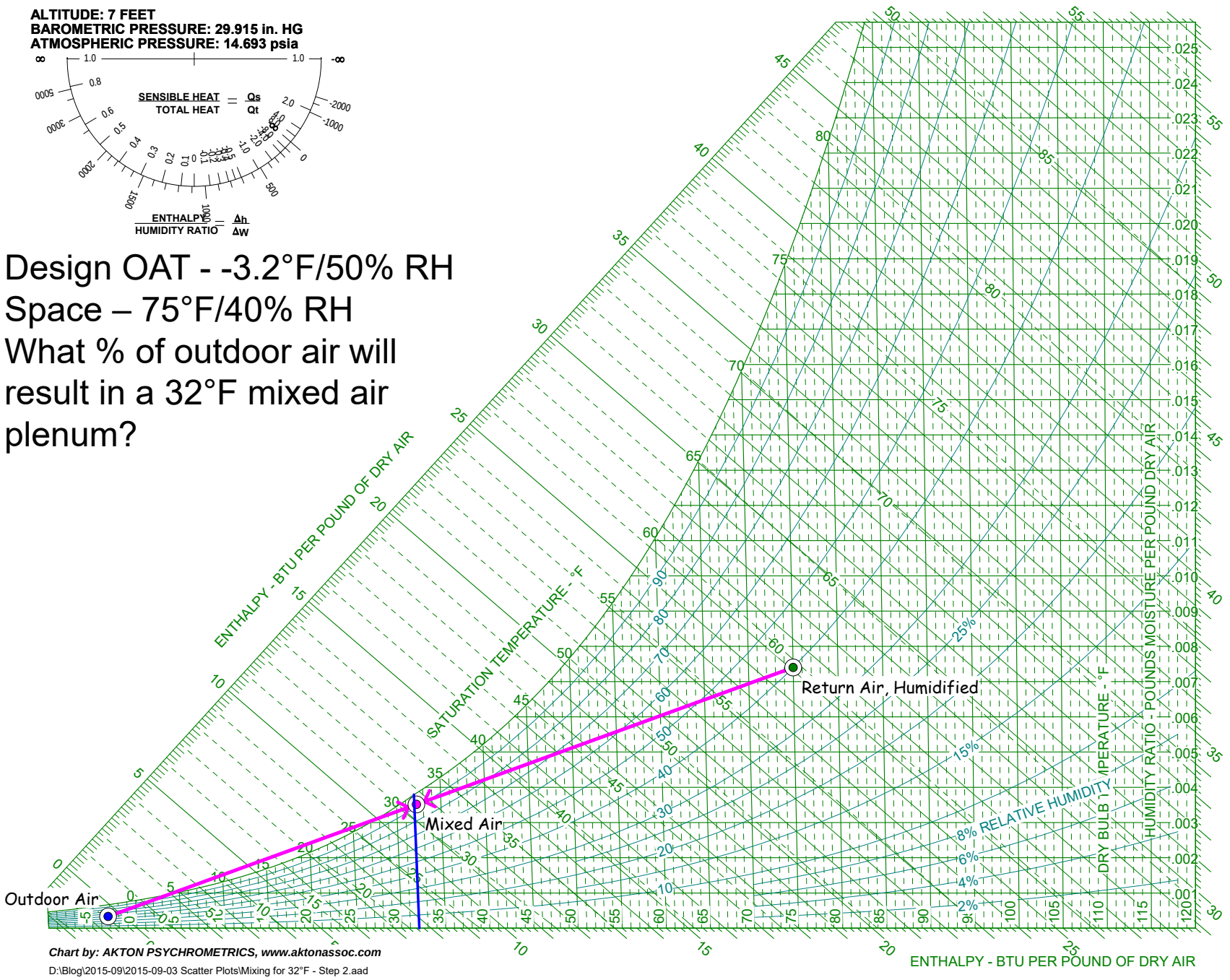
Where $t_{MixedAir}$ is the mixed air temperature created by the given outdoor air and return air temperatures and flow percentages ***assuming perfect mixing.***



A Tool for 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?


ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
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?
Outdoor Air
Mixed Air
Return Air, Humidified
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
25% RELATIVE HUMIDITY
15%
8%
6%
4%
2%
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
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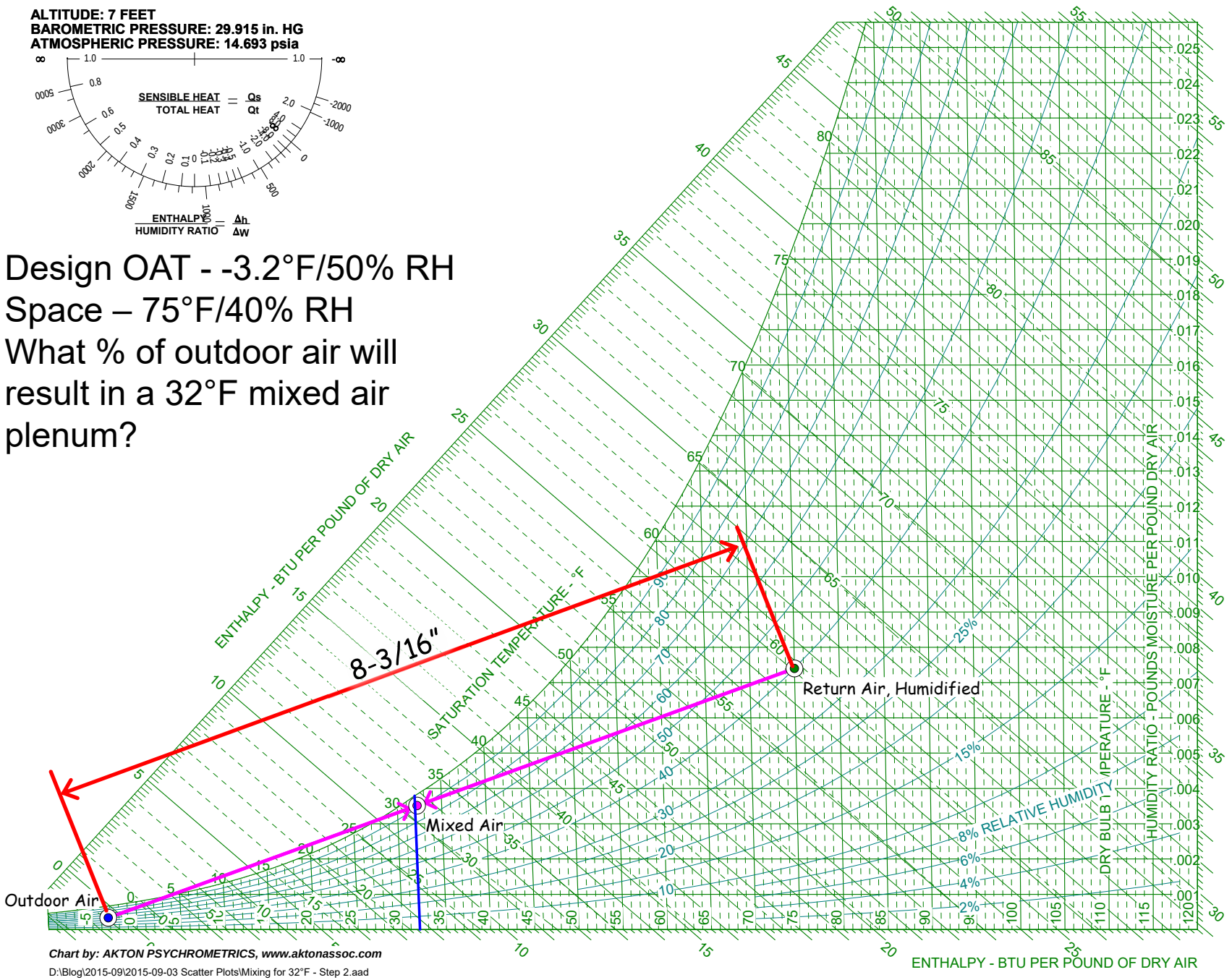
ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Design OAT - -3.2°F/50% RH
Space – 75°F/40% RH
What % of outdoor air will result in a 32°F mixed air plenum?
8-3/16"
Outdoor Air
Mixed Air
Return Air, Humidified
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
8% RELATIVE HUMIDITY
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
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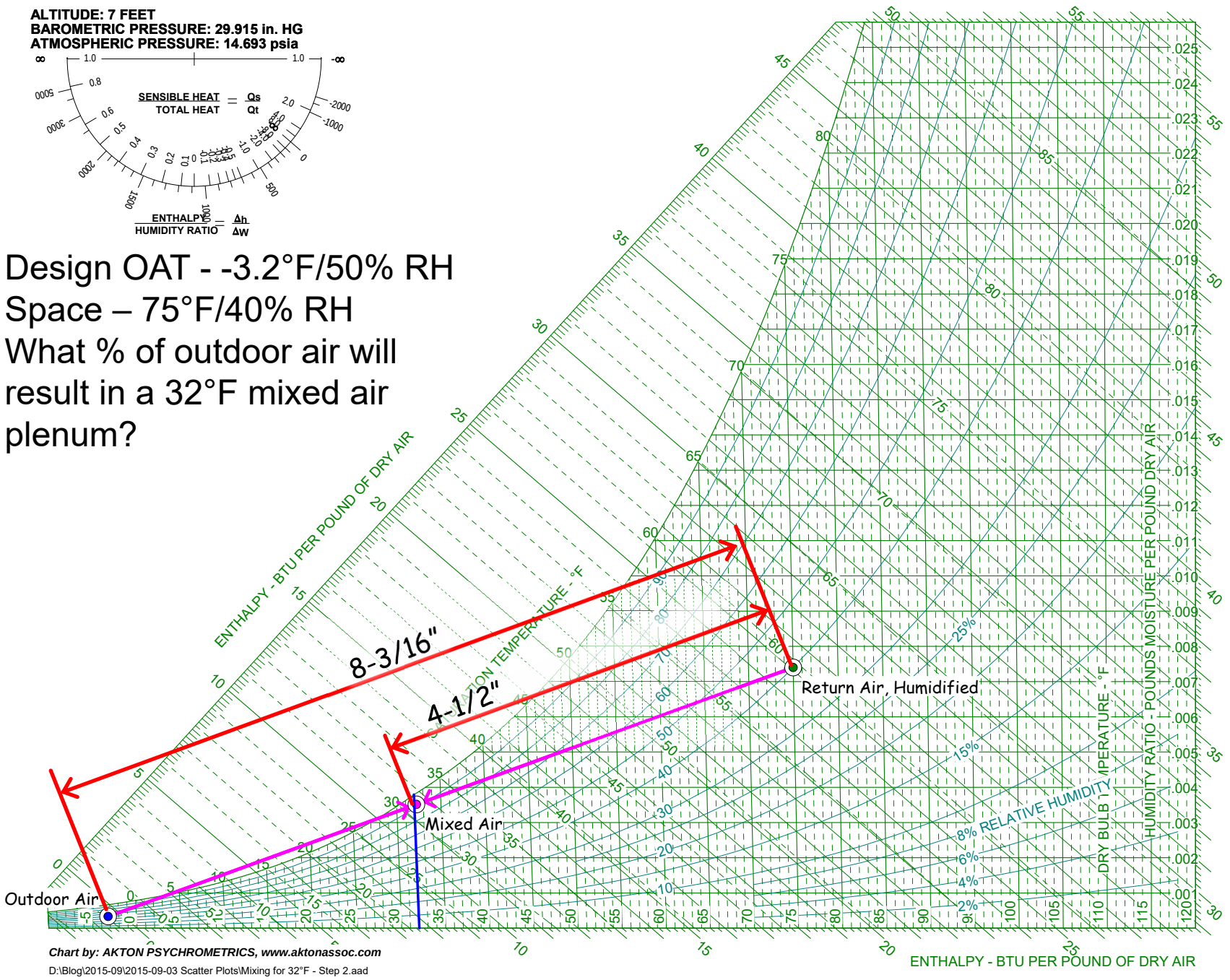
ALTITUDE: 7 FEET
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ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Design OAT - -3.2°F/50% RH
Space – 75°F/40% RH
What % of outdoor air will result in a 32°F mixed air plenum?
8-3/16"
4-1/2"
Outdoor Air
Mixed Air
Return Air, Humidified
ENTHALPY - BTU PER POUND OF DRY AIR
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
DRY BULB TEMPERATURE - °F
8% RELATIVE HUMIDITY
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
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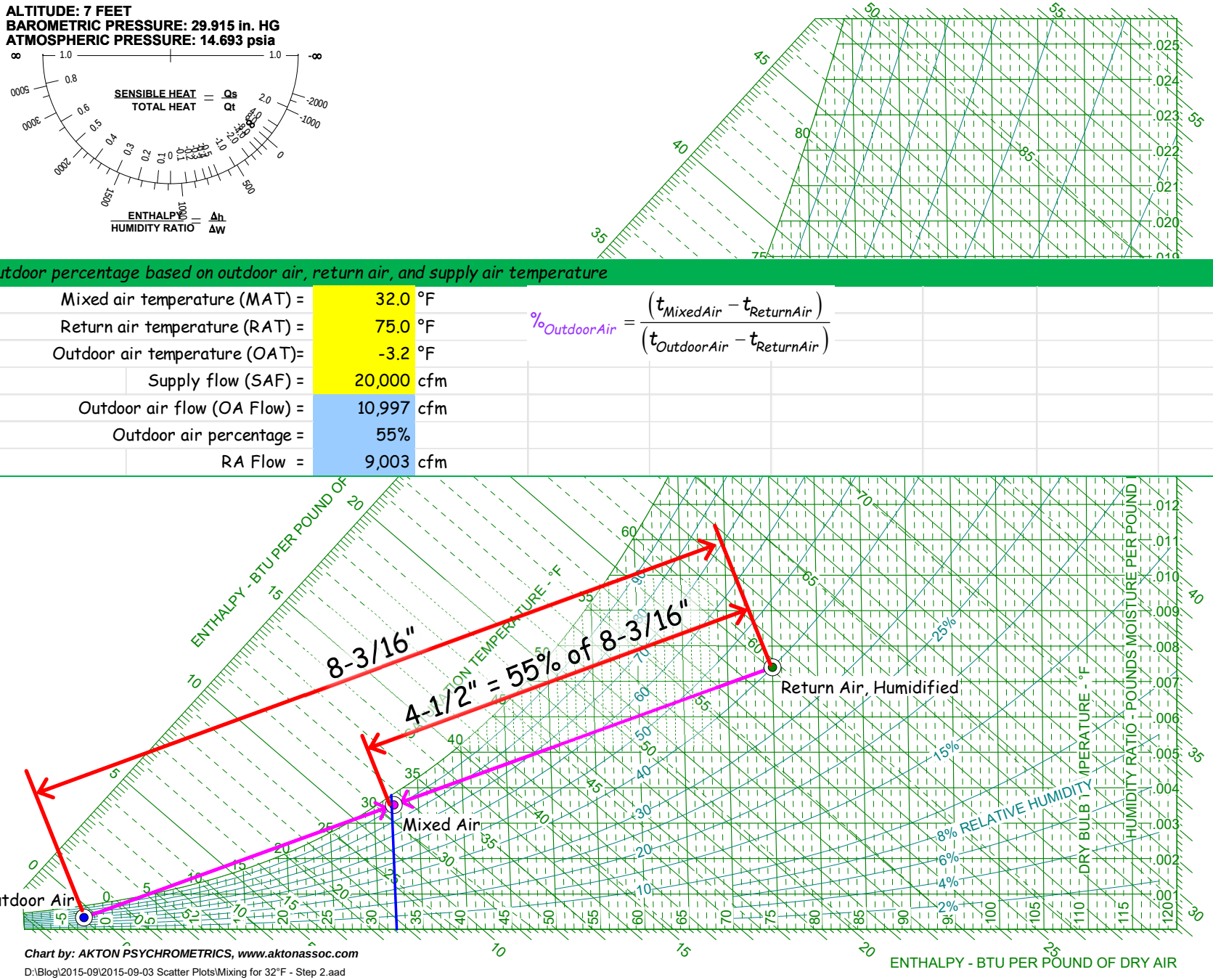
ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Outdoor percentage based on outdoor air, return air, and supply air temperature
Mixed air temperature (MAT) = 32.0 °F
Return air temperature (RAT) = 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 = (tMixedAir − tReturnAir) / (tOutdoorAir − tReturnAir)
8-3/16"
4-1/2" = 55% of 8-3/16"
Return Air, Humidified
Mixed Air
Outdoor Air
ENTHALPY - BTU PER POUND OF DRY AIR
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
DRY BULB TEMPERATURE - °F
8% RELATIVE HUMIDITY
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
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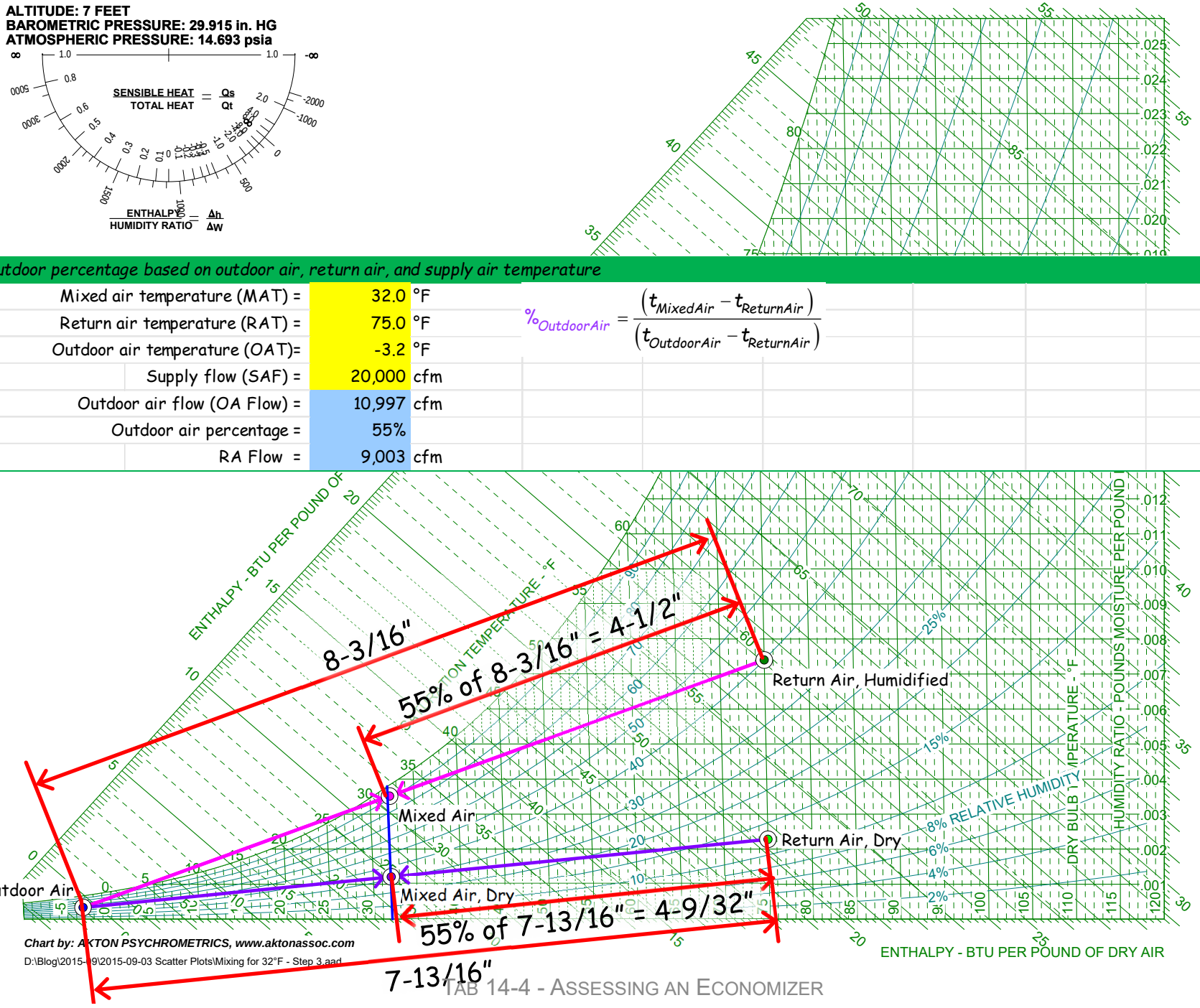
ALTITUDE: 7 FEET
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ENTHALPY / HUMIDITY RATIO = Δh / ΔW
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Outdoor air flow (OA Flow) = 10,997 cfm
Outdoor air percentage = 55%
RA Flow = 9,003 cfm
%OutdoorAir = (tMixedAir − tReturnAir) / (tOutdoorAir − tReturnAir)
8-3/16"
55% of 8-3/16" = 4-1/2"
Return Air, Humidified
Mixed Air
Return Air, Dry
Outdoor Air
Mixed Air, Dry
55% of 7-13/16" = 4-9/32"
7-13/16"
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
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ENTHALPY - BTU PER POUND OF DRY AIR
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
8% RELATIVE HUMIDITY

Assessing the Perfect Economizer Using These Relationships

What is a Perfect Economizer?

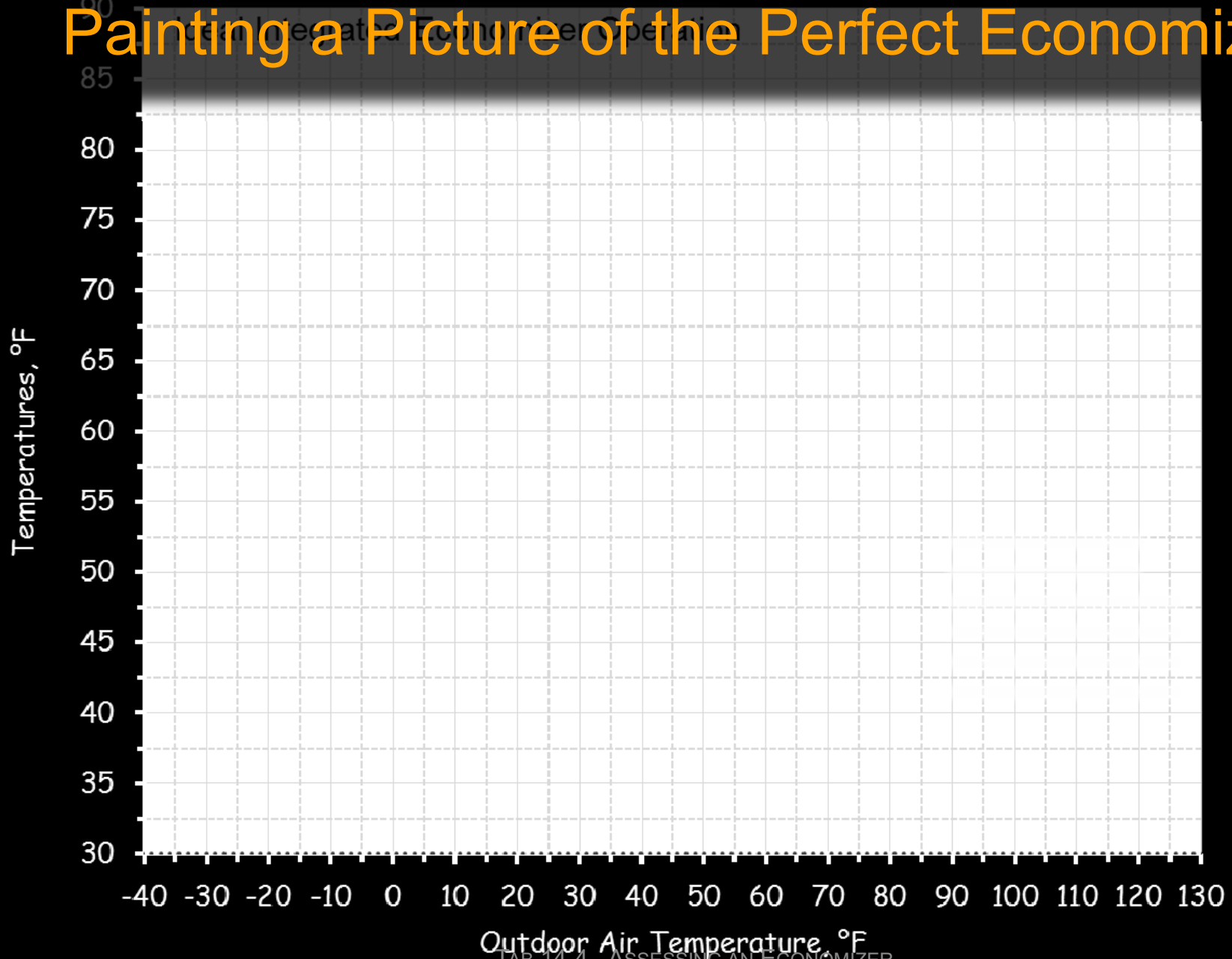
- Does not provide cooling if the preheat process is active
- Promotes good mixing
- Based on the true mixed air temperature
- Set point is properly coordinated with other HVAC processes occurring in the system
- Integrated with mechanical cooling to minimize energy consumption
  - Mechanical cooling not used until outdoor air can not meet set point
  - Outdoor air setting returned to the minimum requirement when outdoor air conditions make it no longer suitable for cooling
- Disabled when the system is not in operation

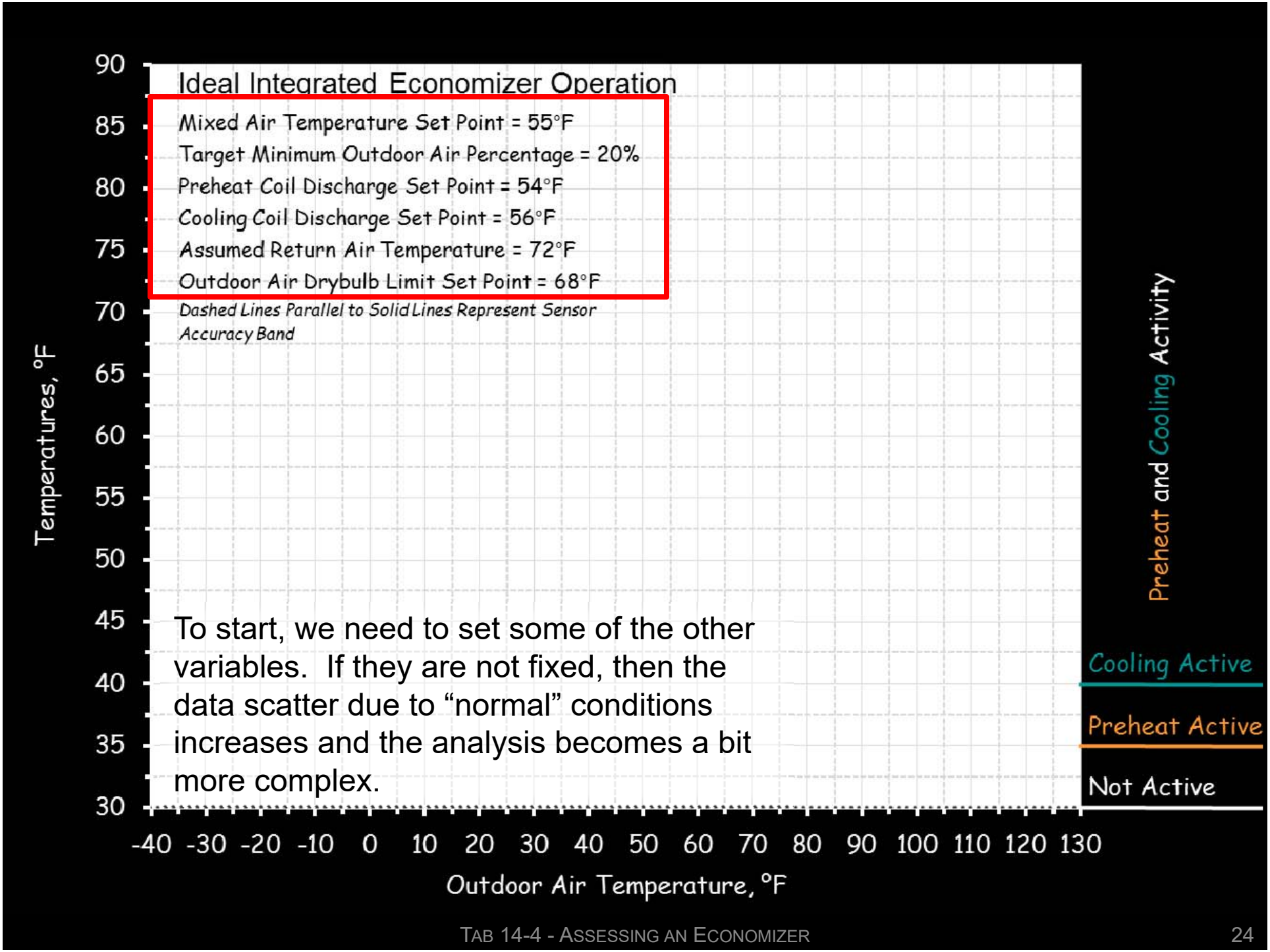
Painting a Picture of the Perfect Economizer

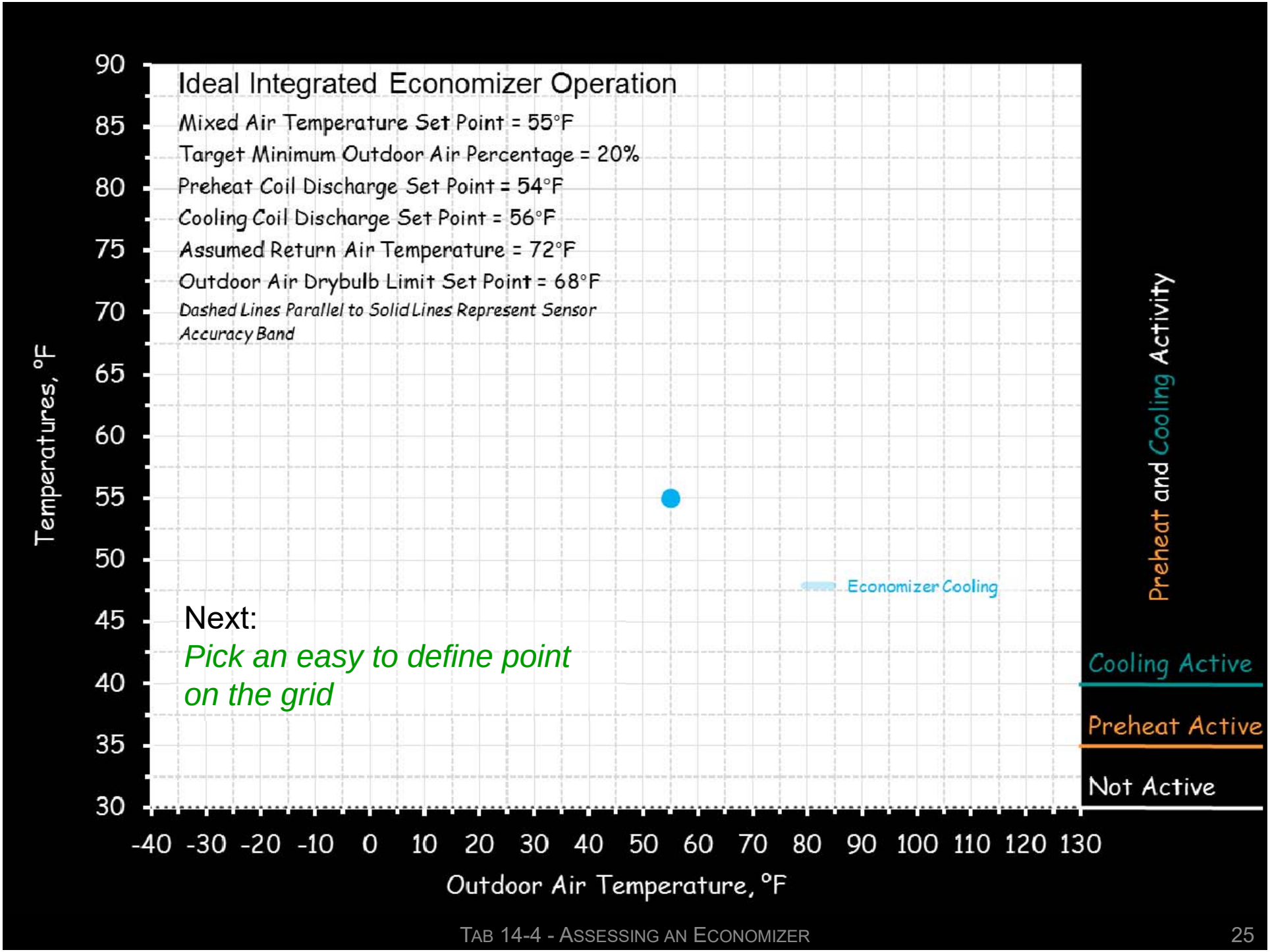
Plot mixed air temperature (the dependent variable) as a function of some other economizer related parameter like outdoor temperature (the independent variable)

- There should be a predictable mixed air temperature for every value of the dependent variable
- The predicted data points for a perfect economizer will draw a line on the graph
- The data points for a real economizer will create a cloud when you plot them
  - Cloud follows the perfect economizer line – Good
  - Cloud *doesn't* follow the perfect economizer line – Bad (and a clue about What is Wrong)

Painting a Picture of the Perfect Economizer




Ideal Integrated Economizer Operation
Mixed Air Temperature Set Point = 55°F
Target Minimum Outdoor Air Percentage = 20%
Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
To start, we need to set some of the other variables. If they are not fixed, then the data scatter due to "normal" conditions increases and the analysis becomes a bit more complex.
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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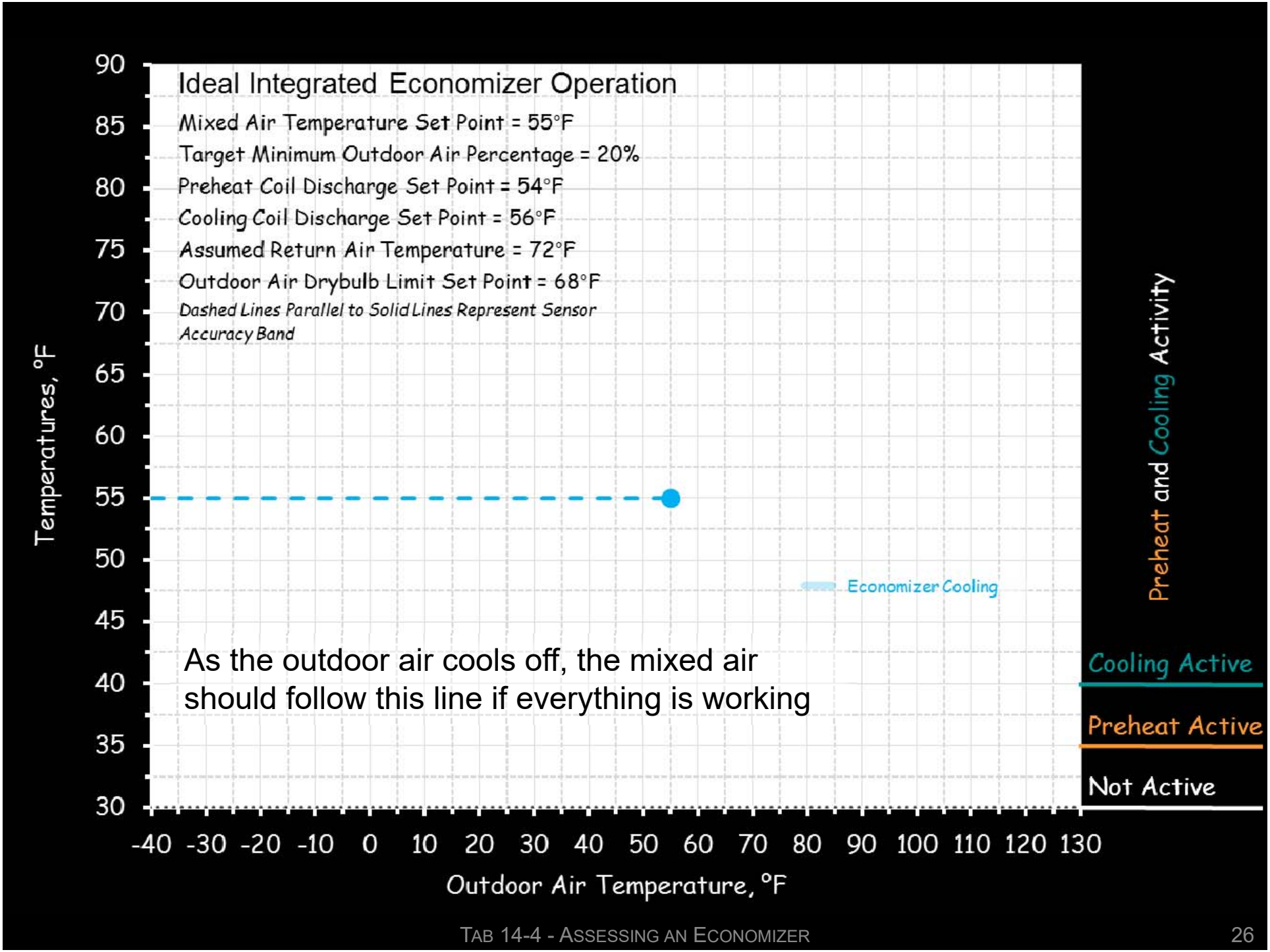
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Economizer Cooling
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active
Next:
Pick an easy to define point on the grid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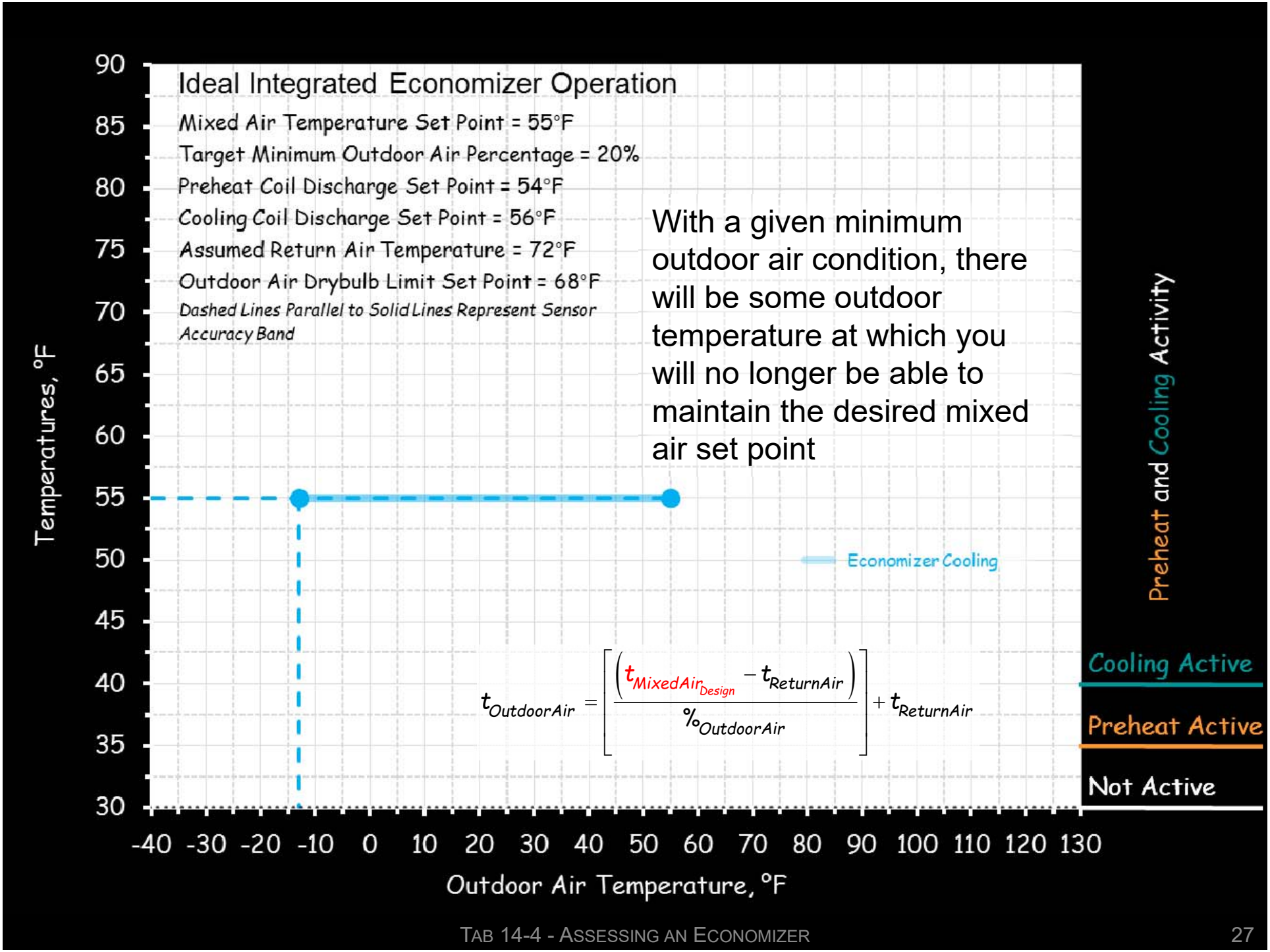
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Economizer Cooling
As the outdoor air cools off, the mixed air should follow this line if everything is working
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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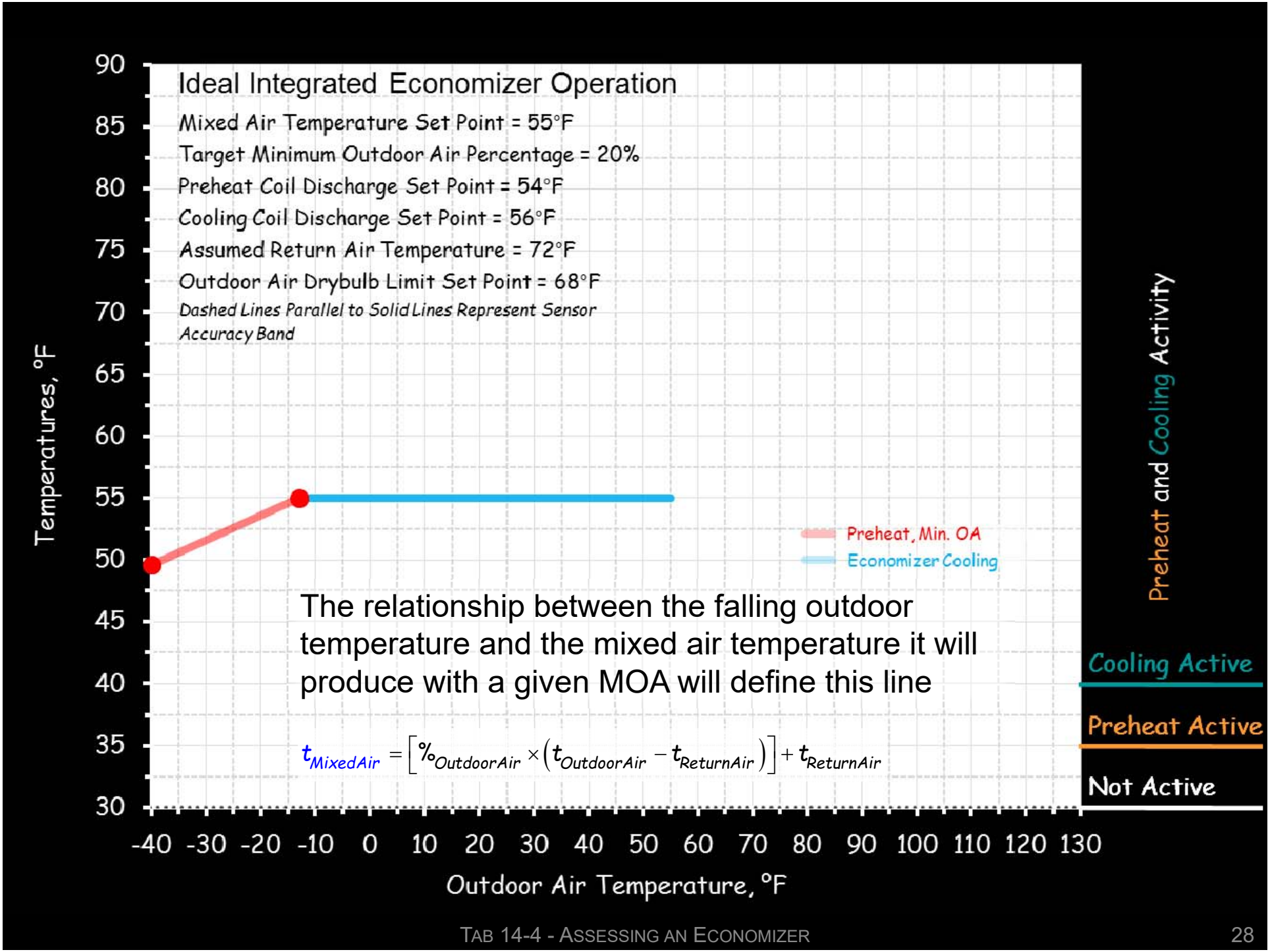
Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
With a given minimum outdoor air condition, there will be some outdoor temperature at which you will no longer be able to maintain the desired mixed air set point
Economizer Cooling
$t_{OutdoorAir} = \left[\frac{\left(t_{MixedAir_{Design}} - t_{ReturnAir}\right)}{\%_{OutdoorAir}}\right] + t_{ReturnAir}$
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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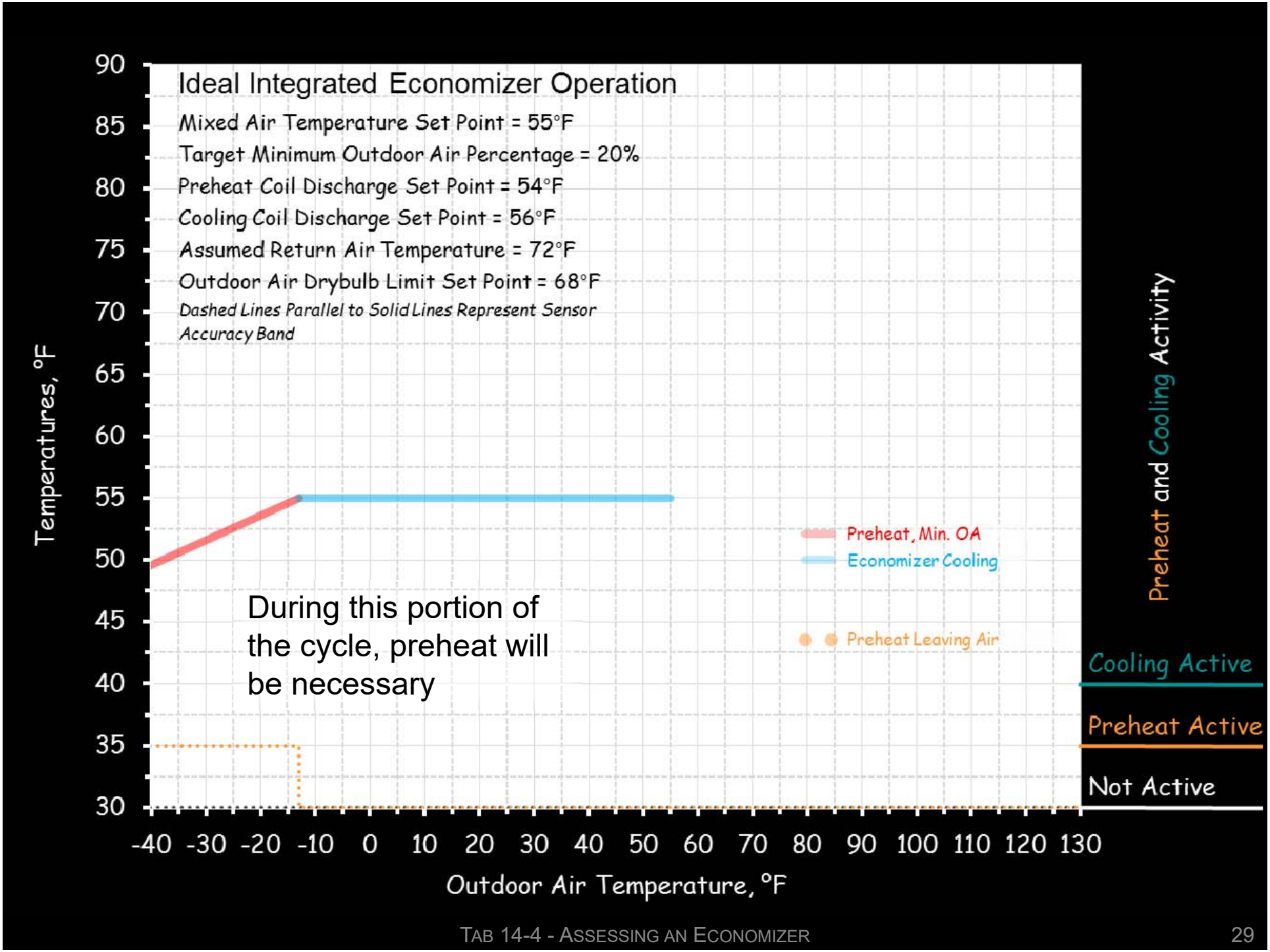
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
The relationship between the falling outdoor temperature and the mixed air temperature it will produce with a given MOA will define this line
$t_{MixedAir} = \left[\%_{OutdoorAir} \times \left(t_{OutdoorAir} - t_{ReturnAir}\right)\right] + t_{ReturnAir}$
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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Temperatures, °F
90
85
80
75
70
65
60
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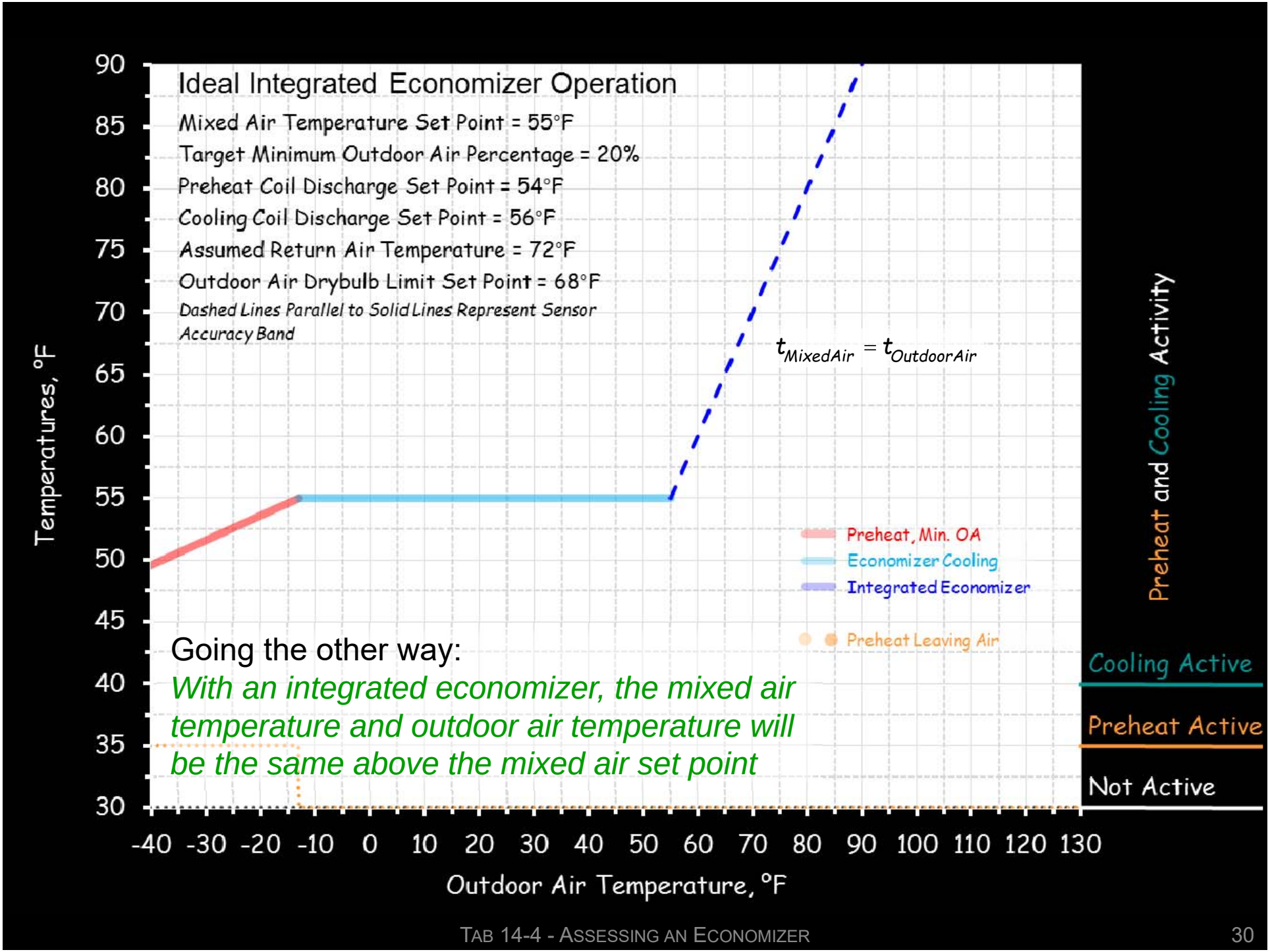
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
Preheat Leaving Air
During this portion of the cycle, preheat will be necessary
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
$t_{MixedAir} = t_{OutdoorAir}$
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Preheat Leaving Air
Going the other way:
With an integrated economizer, the mixed air temperature and outdoor air temperature will be the same above the mixed air set point
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
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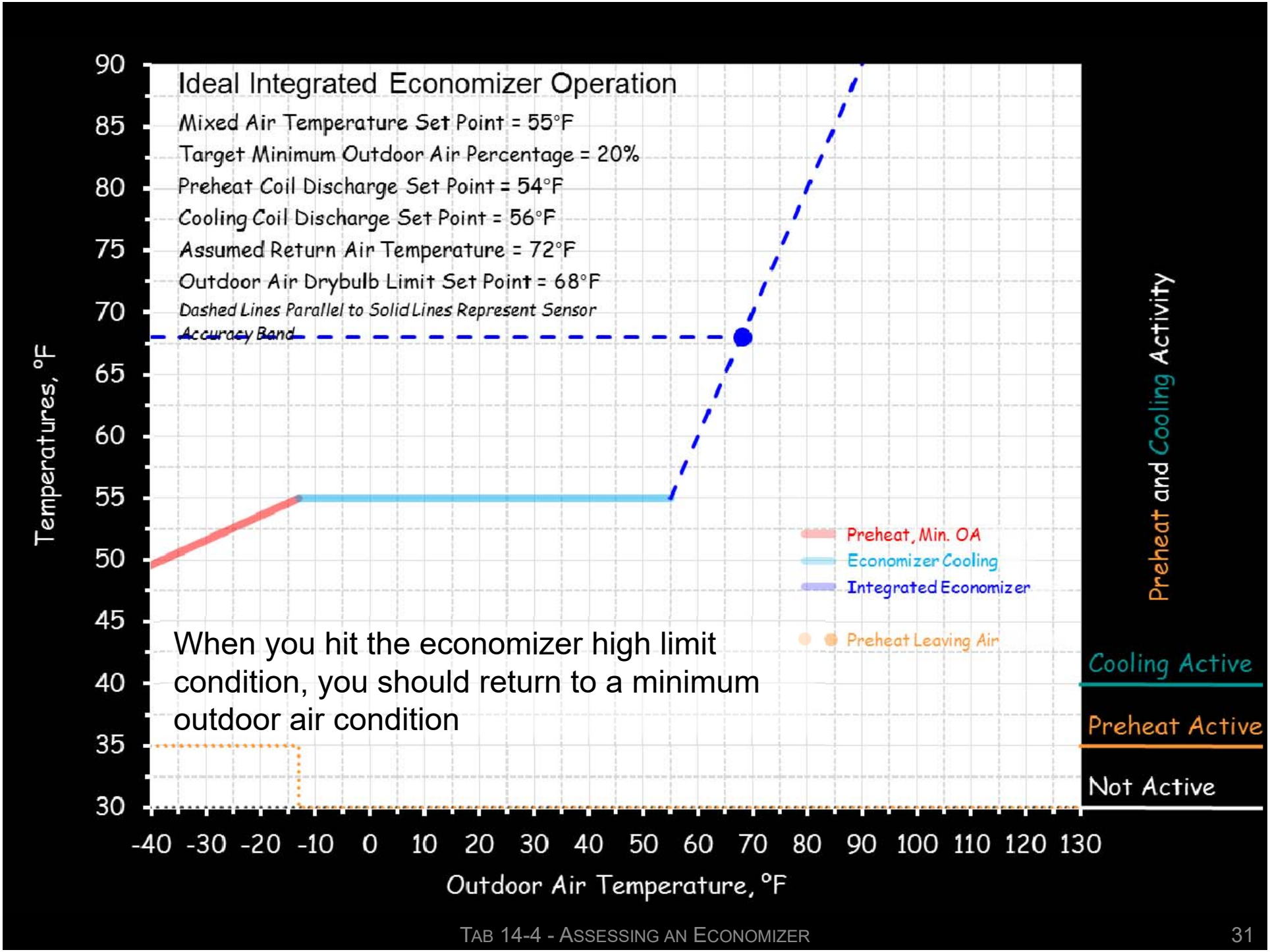
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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60
55
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45
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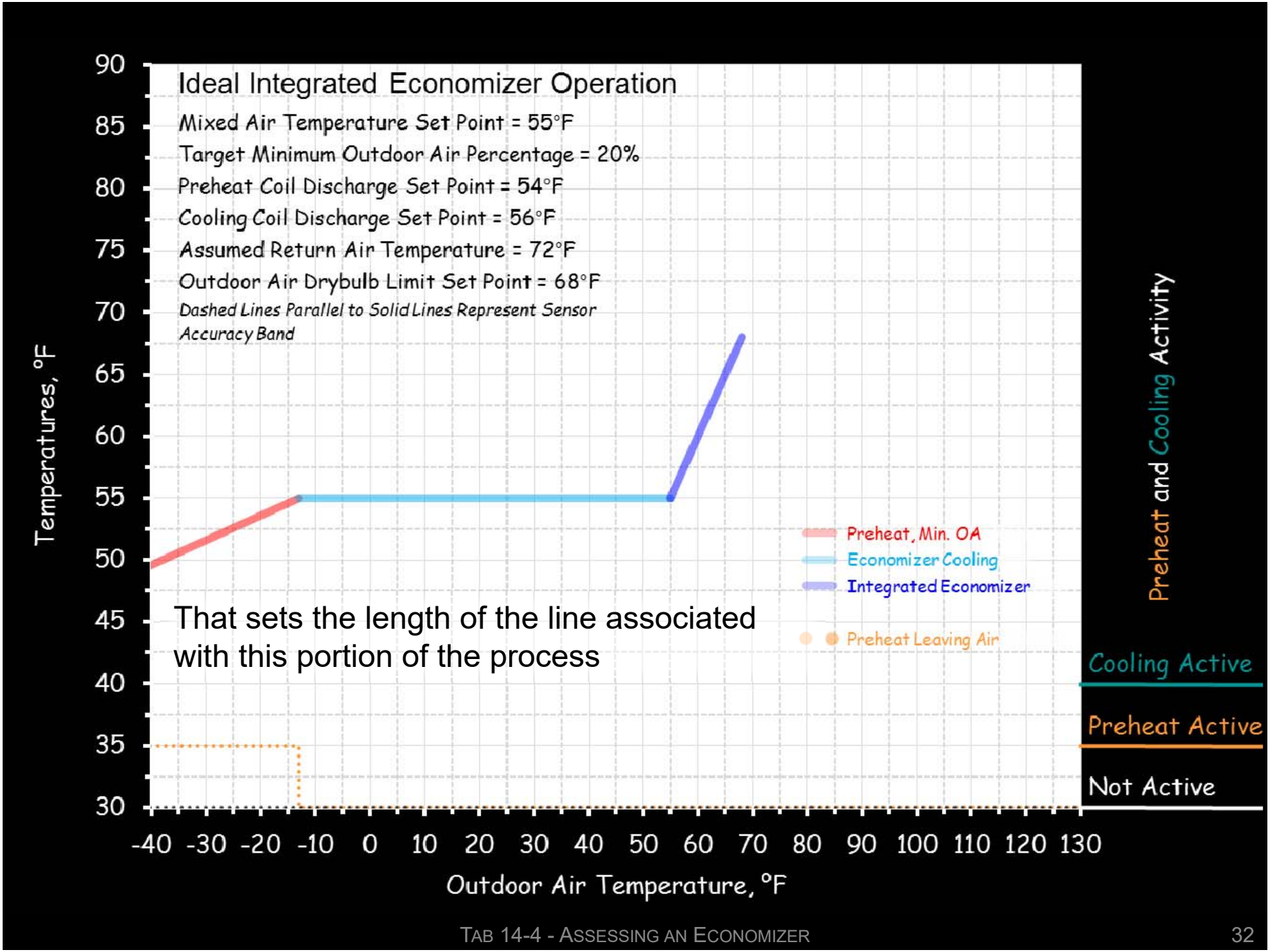
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Preheat Leaving Air
When you hit the economizer high limit condition, you should return to a minimum outdoor air condition
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active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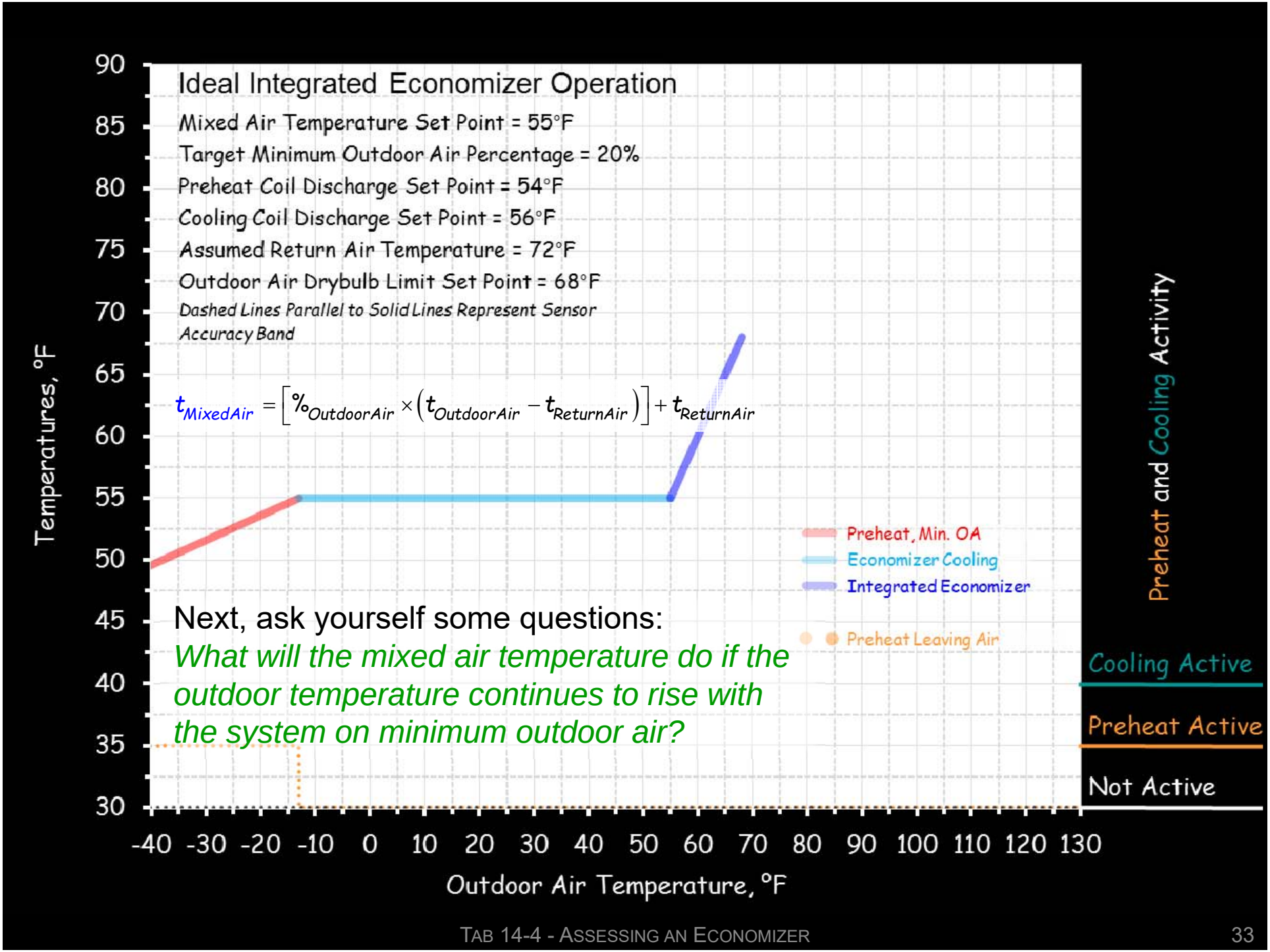
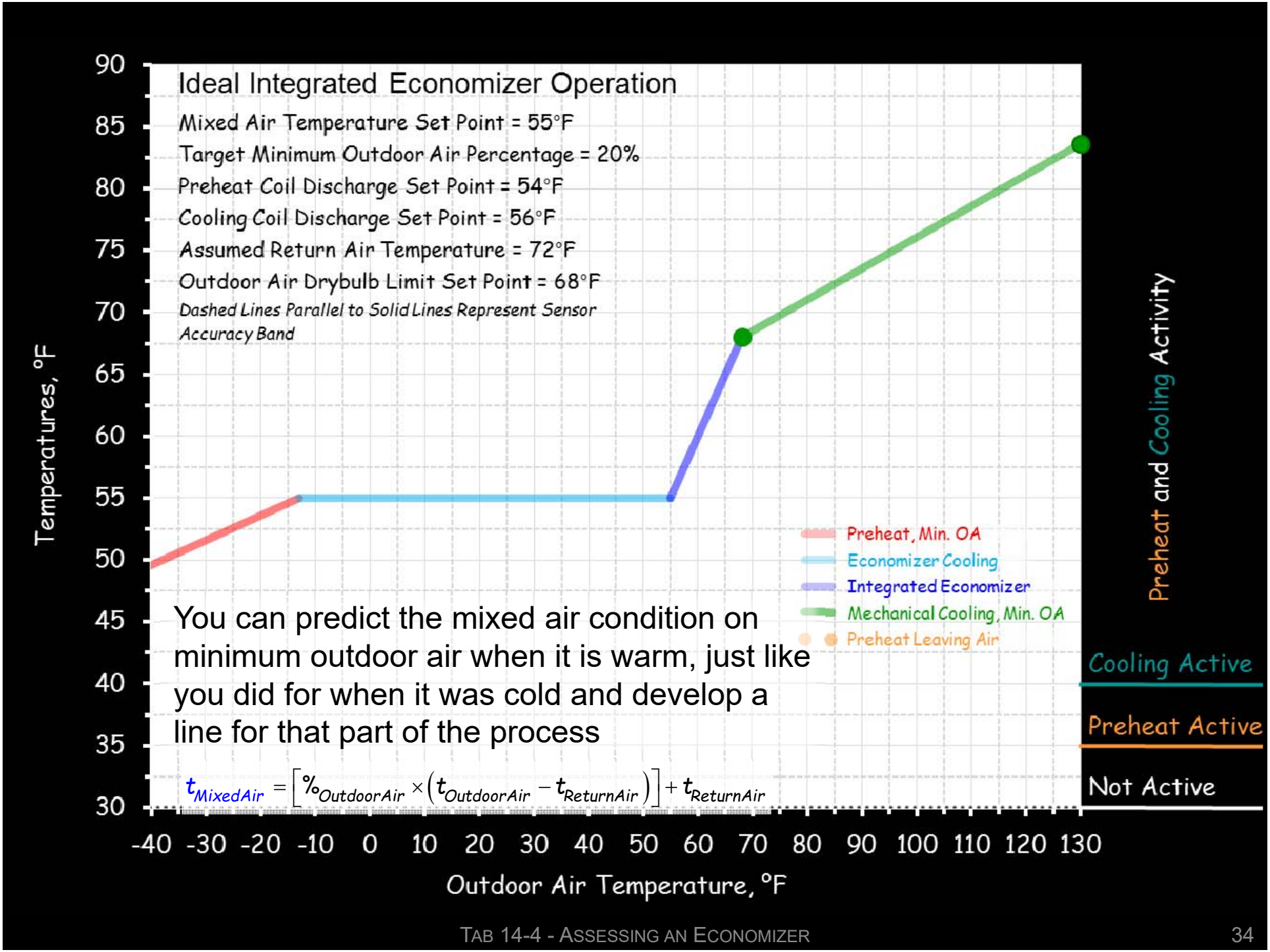
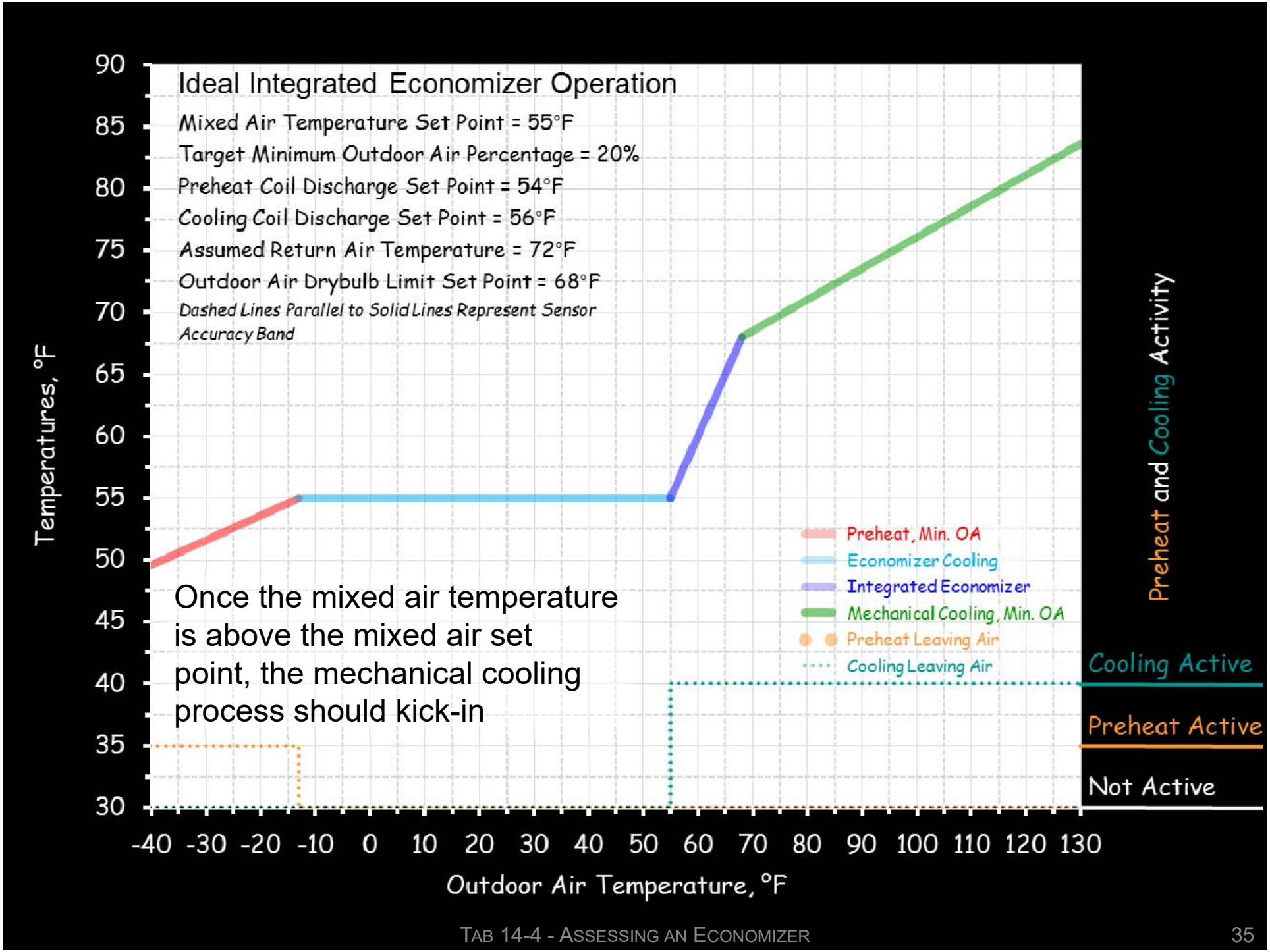
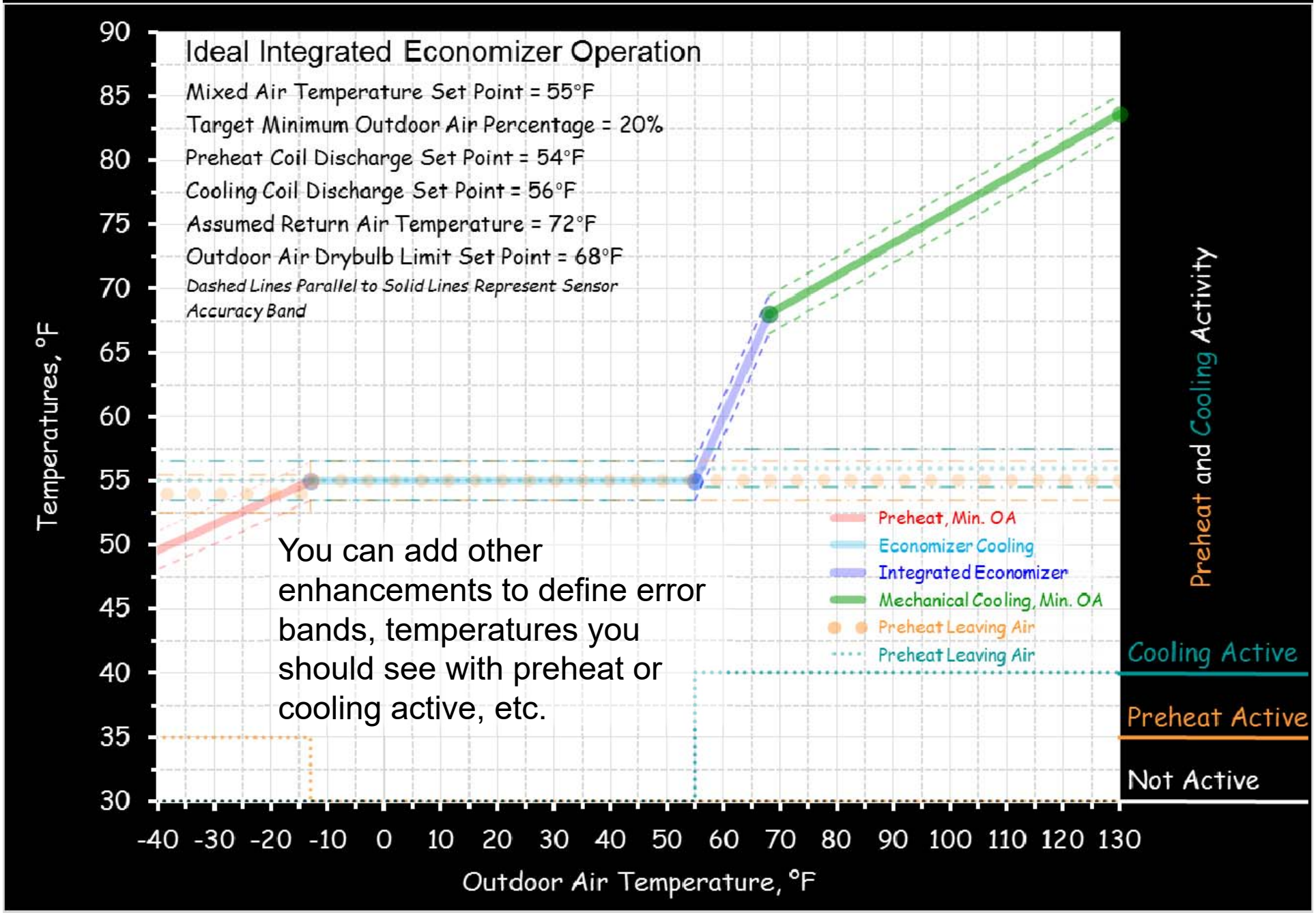
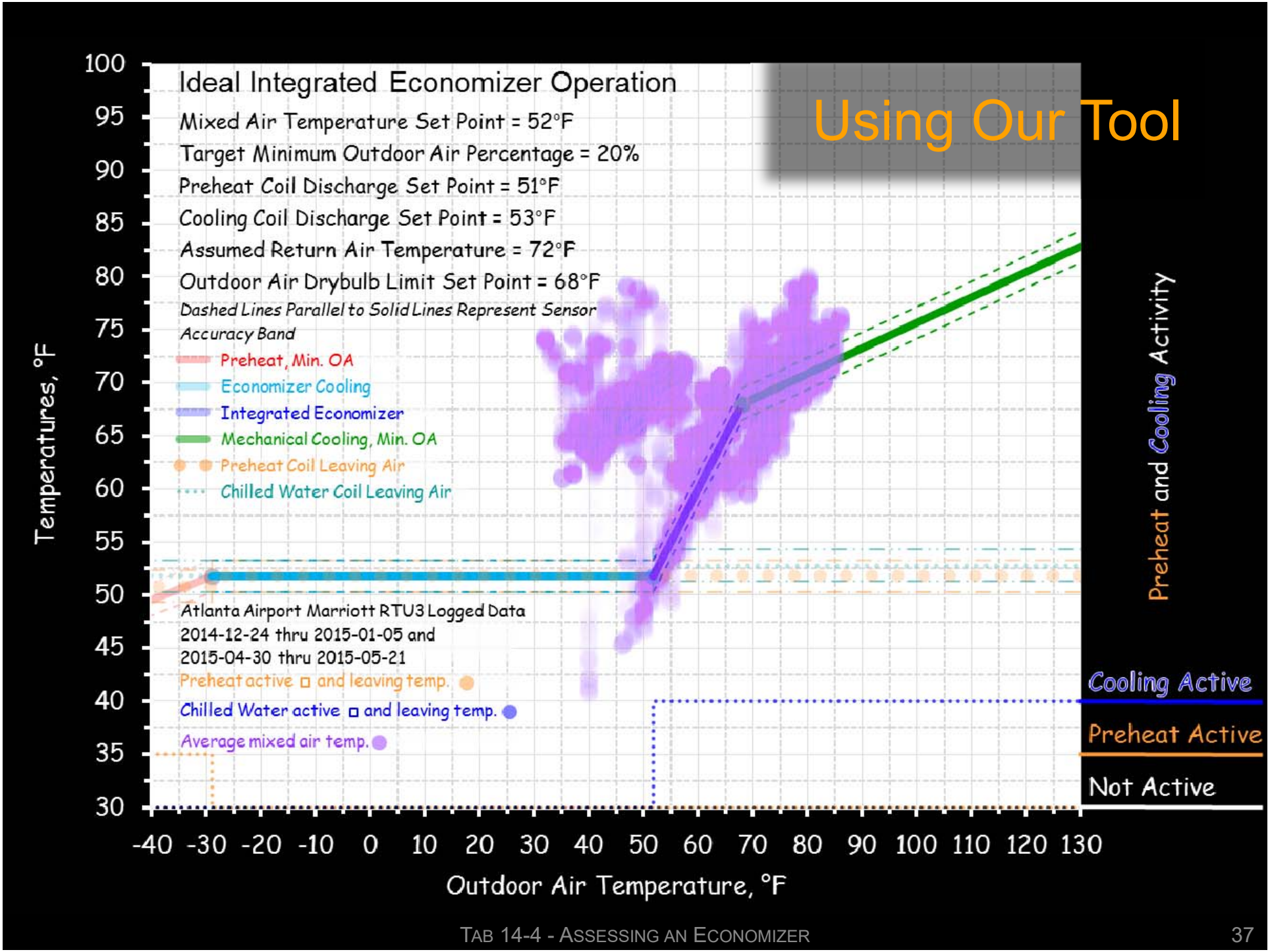
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Preheat Leaving Air
That sets the length of the line associated with this portion of the process
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active


Ideal Integrated Economizer Operation
Mixed Air Temperature Set Point = 55°F
Target Minimum Outdoor Air Percentage = 20%
Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
$t_{MixedAir} = \left[\%_{OutdoorAir} \times \left(t_{OutdoorAir} - t_{ReturnAir}\right)\right] + t_{ReturnAir}$
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Preheat Leaving Air
Next, ask yourself some questions:
What will the mixed air temperature do if the outdoor temperature continues to rise with the system on minimum outdoor air?
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active

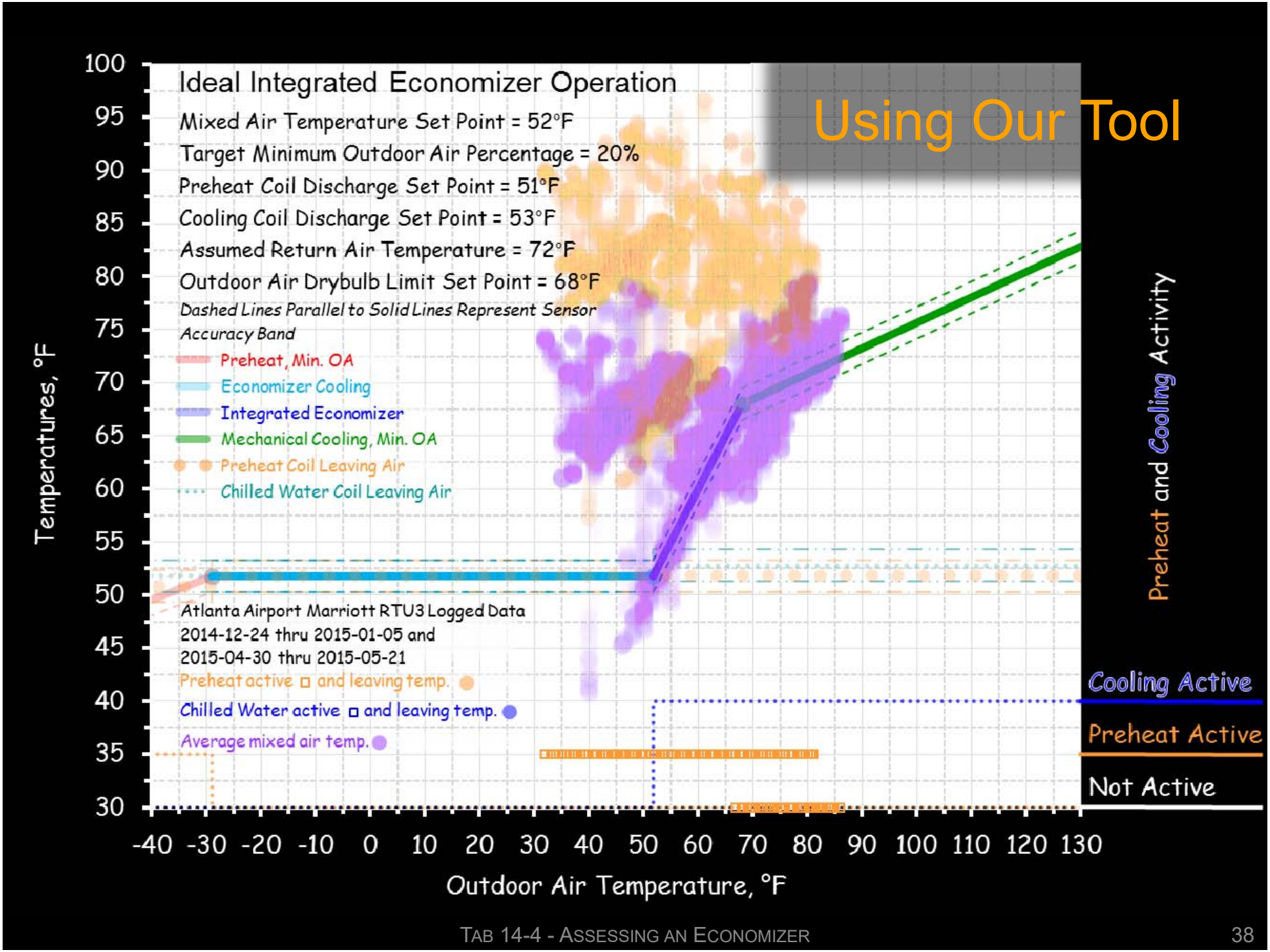

Ideal Integrated Economizer Operation
Mixed Air Temperature Set Point = 55°F
Target Minimum Outdoor Air Percentage = 20%
Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Mechanical Cooling, Min. OA
Preheat Leaving Air
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active
You can predict the mixed air condition on minimum outdoor air when it is warm, just like you did for when it was cold and develop a line for that part of the process
$t_{MixedAir} = \left[\%_{OutdoorAir} \times \left(t_{OutdoorAir} - t_{ReturnAir}\right)\right] + t_{ReturnAir}$


Ideal Integrated Economizer Operation
Mixed Air Temperature Set Point = 55°F
Target Minimum Outdoor Air Percentage = 20%
Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Mechanical Cooling, Min. OA
Preheat Leaving Air
Cooling Leaving Air
Once the mixed air temperature is above the mixed air set point, the mechanical cooling process should kick-in
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active

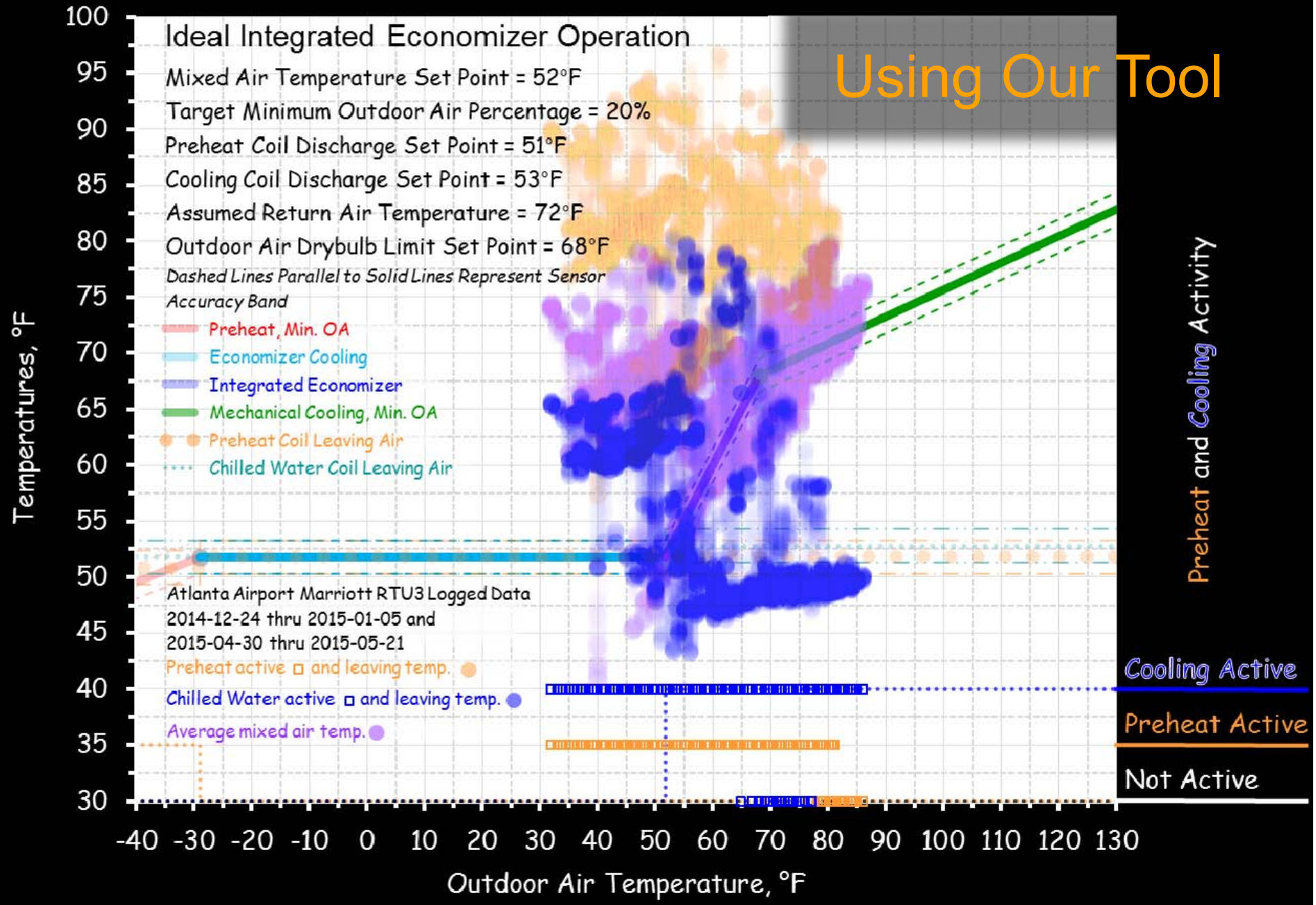

Ideal Integrated Economizer Operation
Mixed Air Temperature Set Point = 55°F
Target Minimum Outdoor Air Percentage = 20%
Preheat Coil Discharge Set Point = 54°F
Cooling Coil Discharge Set Point = 56°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Temperatures, °F
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
You can add other enhancements to define error bands, temperatures you should see with preheat or cooling active, etc.
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Mechanical Cooling, Min. OA
Preheat Leaving Air
Preheat Leaving Air
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active

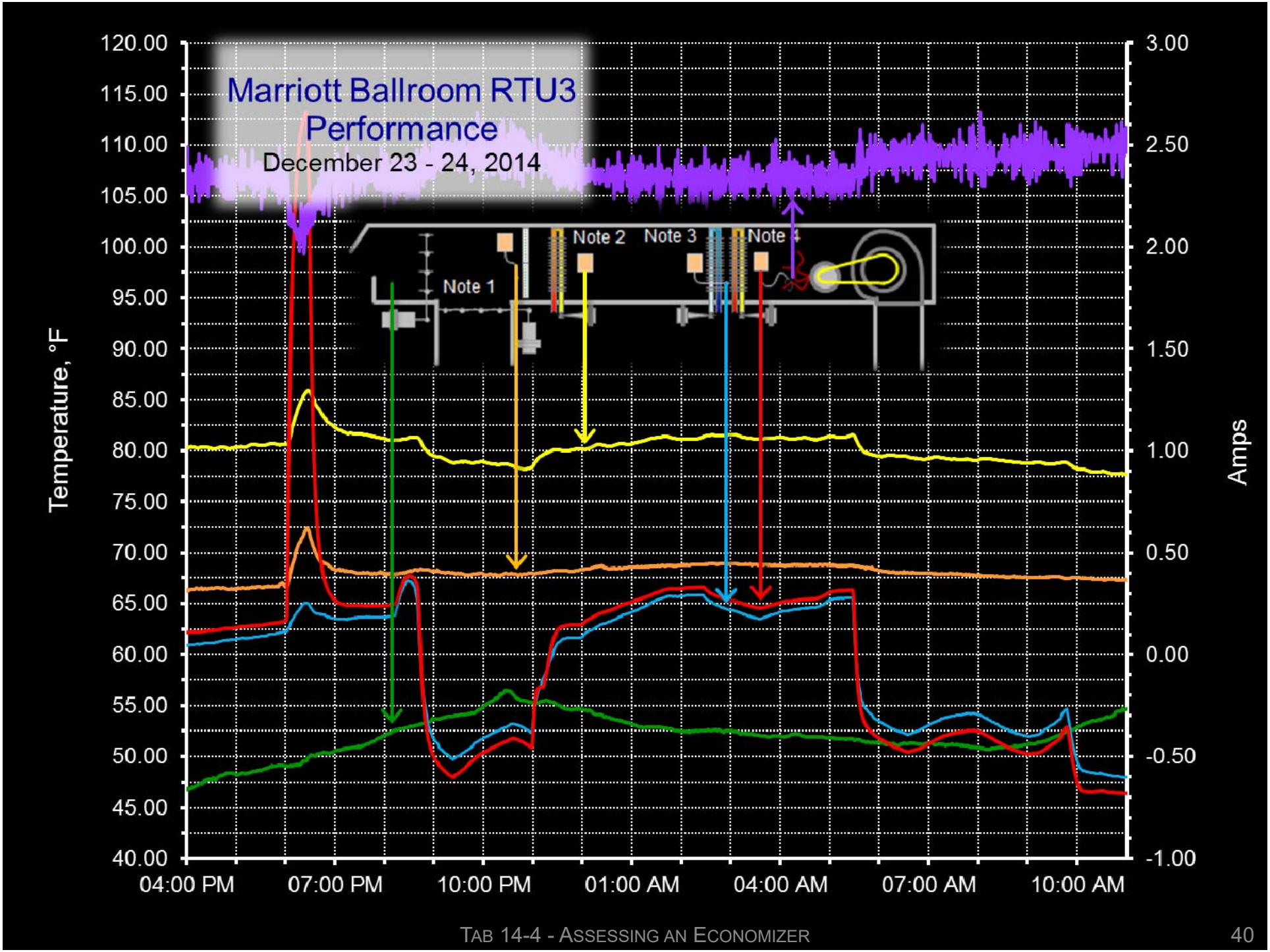


Using Our Tool


Ideal Integrated Economizer Operation
Mixed Air Temperature Set Point = 52°F
Target Minimum Outdoor Air Percentage = 20%
Preheat Coil Discharge Set Point = 51°F
Cooling Coil Discharge Set Point = 53°F
Assumed Return Air Temperature = 72°F
Outdoor Air Drybulb Limit Set Point = 68°F
Dashed Lines Parallel to Solid Lines Represent Sensor Accuracy Band
Preheat, Min. OA
Economizer Cooling
Integrated Economizer
Mechanical Cooling, Min. OA
Preheat Coil Leaving Air
Chilled Water Coil Leaving Air
Atlanta Airport Marriott RTU3 Logged Data
2014-12-24 thru 2015-01-05 and
2015-04-30 thru 2015-05-21
Preheat active and leaving temp.
Chilled Water active and leaving temp.
Average mixed air temp.
Temperatures, °F
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Outdoor Air Temperature, °F
Using Our Tool
Preheat and Cooling Activity
Cooling Active
Preheat Active
Not Active

Using Our Tool




Marriott Ballroom RTU3
Performance
December 23 - 24, 2014
Note 1
Note 2
Note 3
Note 4
Temperature, °F
Amps
120.00
115.00
110.00
105.00
100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
04:00 PM
07:00 PM
10:00 PM
01:00 AM
04:00 AM
07:00 AM
10:00 AM

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