NBCIP

What You Need to Know About Critical Control Sensors

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Iowa Energy Center

Presented at the Pacific Energy Center

May 13, 2006

National Building Controls Information Program

Outline

- **Introduction**
- **Part 1: Relative Humidity Sensors**
- **Part 2: Economizer Sensors**
- **Part 3: CO2 Sensors**

Introduction

- Iowa Energy Center
- DDC Online
- NBCIP

National Building Controls Information Program

Iowa Energy Center

- **Mission**
  - Conduct and sponsor research, demonstration and education programs in the areas of energy efficiency and renewable energy

- **Commercial Buildings Energy Efficiency Program**
  - Focal point is the Energy Resource Station

Energy Resource Station

- 4 Matched Pairs of Test Rooms
- Side by Side Testing

Testing Partners

- Iowa State University
- University of Iowa
- Purdue University
- Massachusetts Institute of Technology
- Loughborough University, UK
- University of Nebraska-Omaha
- Johnson Controls, Inc.
- Siemens Building Technologies
- Architectural Energy Corporation
- Federspiel Controls
- Lighting Research Center
- Energy Center of Wisconsin
- National Institute of Standards and Technology
- Lawrence Berkeley National Laboratory
- International Energy Agency Task 22, 34 & 43 – Building Energy Analysis Tools

Universities

Private Companies

National Labs

Energy Organizations

Many Projects have been Building Controls Related

Fast Forward to Today

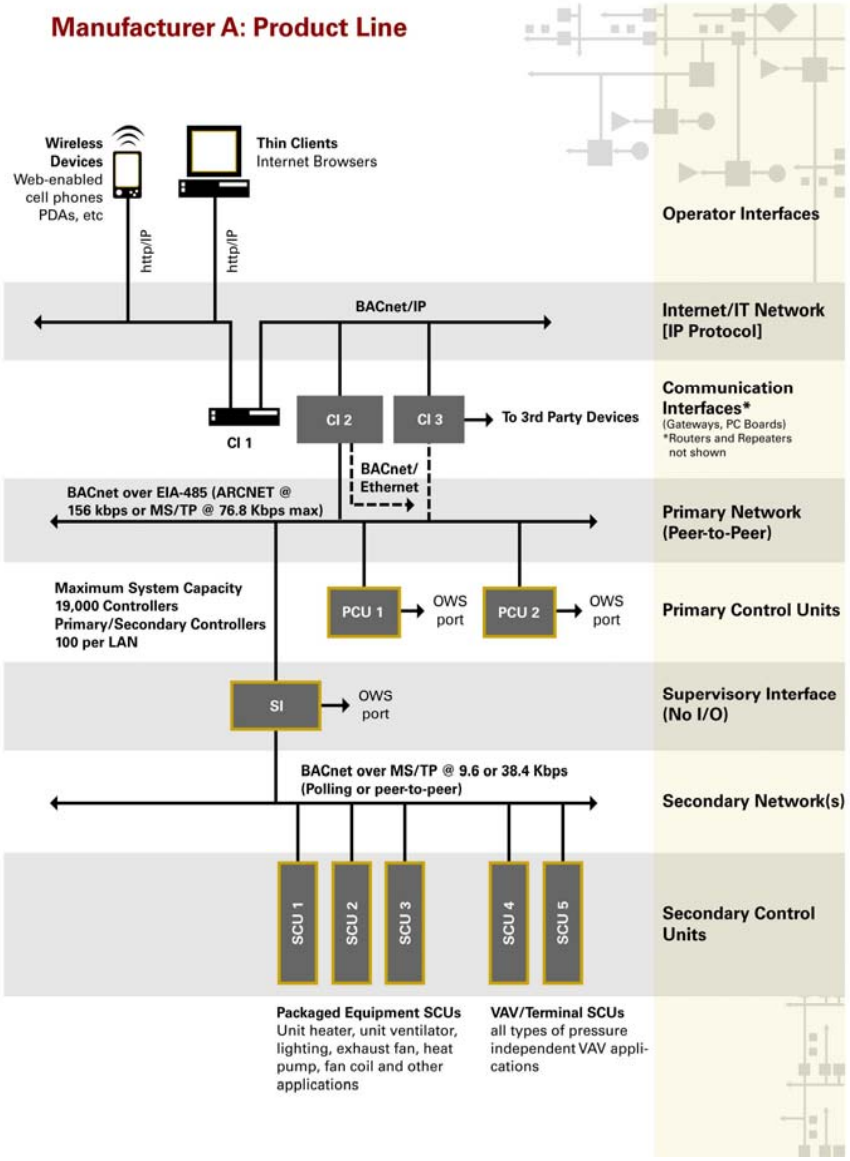
- **Emphasis on Building Controls**
  - Problems associated with building control and operation are big contributors to energy waste in buildings
  - Lack of understanding of building control systems is a primary reason for control and operation problems
  - Our solution – get credible information on building controls into the hands of owners, designers, installers, operators, etc.
    - DDC Online
    - National Building Controls Information Program

DDC Online

- **Generic Technical Information on DDC Systems**
  - Elements of a DDC System
  - Input / Output Devices
  - Controlled Devices
  - Controllers
- **On-line Comparison of DDC Systems**
  - Products presented in a generic framework with consistent terminology
  - Information based on manufacturer reported data

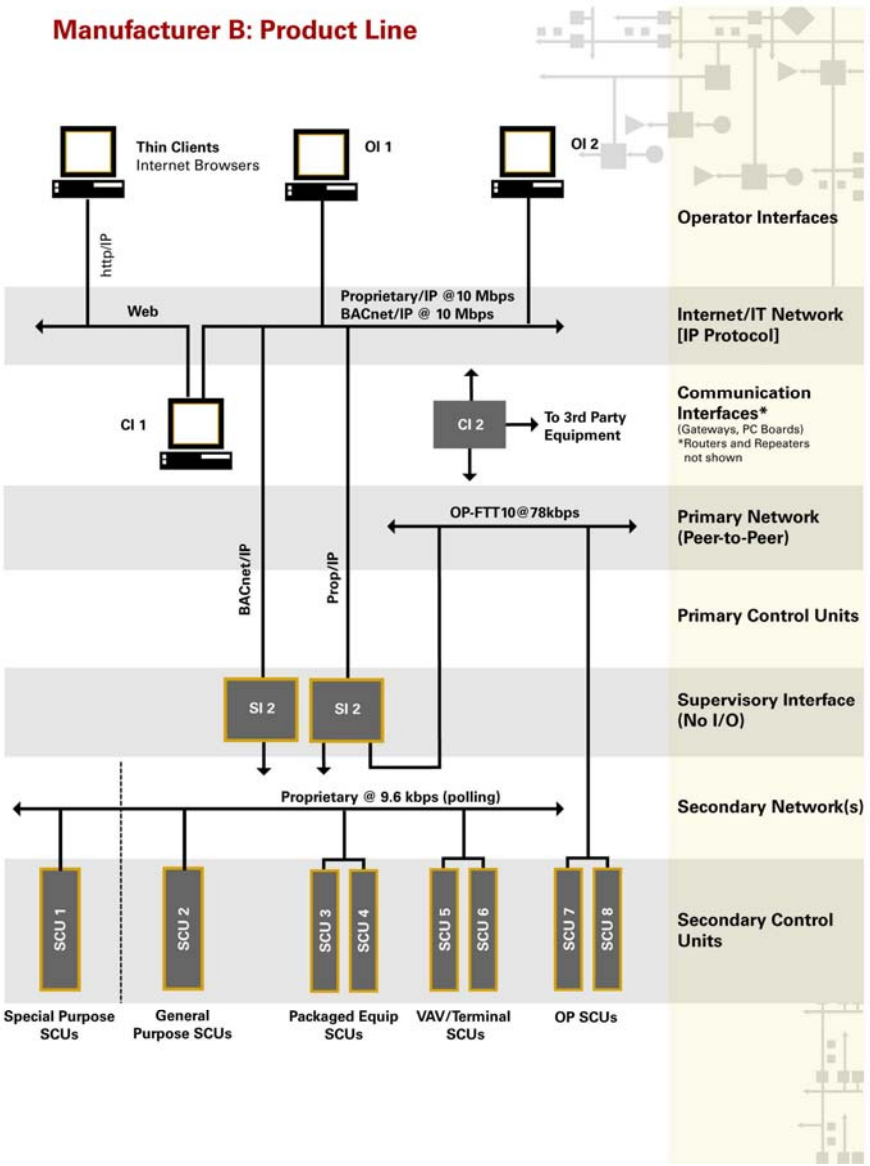
DDC Online

Manufacturer A: Product Line



DDC Online

Manufacturer B: Product Line



National Building Controls Information Program

- **Goal**
  - Facilitate the adoption of energy efficient control products and strategies through product testing, demonstration, education and best practices information dissemination
- **Sponsors**
  - California Energy Commission
  - NSTAR Electric and Gas Corporation
  - Iowa Energy Center
- **Product Testing**
  - Relative Humidity Transmitters
  - Economizer Sensors
  - CO_2 Sensors

Part 1:
Relative Humidity Sensors

- Why Accuracy Matters
- Sensor Technologies
- Testing Procedures
- Results

National Building Controls Information Program

Relative Humidity Transmitters

- **Why Test Them? … Accuracy Matters**
  - Experience indicates their performance is suspect, at best
  - Significant consequences from poor control of relative humidity
    - Damage to precious books and artifacts in libraries and museums (tolerances of ± 5% to ± 10% RH are common)
    - Loss of product in industrial facilities (e.g., printing plants have tight RH tolerances)
    - Mold and mildew problems
    - Energy waste

Relative Humidity Transmitters

- **Examples of Energy Waste**
  - Supermarkets - space humidity has a significant affect on energy use
    - Excessive load on display cases
    - Anti-sweat heaters run more frequently
    - Defrost cycles are more frequent
  - Data Centers – CRAC units have been known to fight each other (one unit humidifying, another dehumidifying) due to RH transmitter drift
  - Buildings With Enthalpy-Based Economizers – using outdoor air when return air should be used (and vice versa)

Relative Humidity Transmitters

- **Testing Process**
  - Develop method of test and obtain external peer review
  - Set up test apparatus and instrumentation
  - Procure devices to be tested
  - Test according to approved method of test
  - Report

Relative Humidity Transmitters

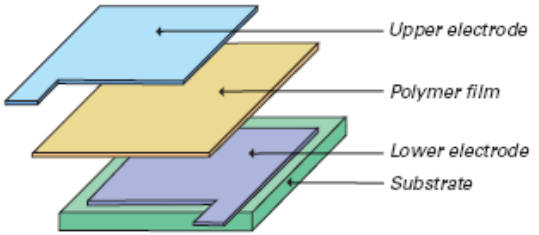
- **Testing for:**
  - Accuracy
  - Linearity
  - Repeatability
  - Response Time
  - Drift
  - Aging Characteristics
  - Stress Conditions

Relative Humidity Transmitters

- **Specifications for the Tested RH Transmitters**
  - Duct-mounted
  - HVAC grade (±3 % accuracy)
  - 0-10 VDC output
  - 24 VDC input

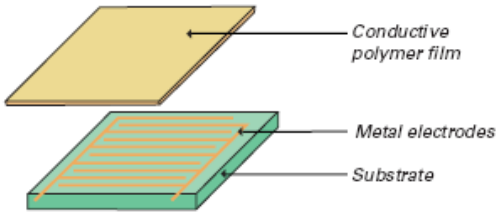
Relative Humidity Transmitters

- **Sensor Technologies for HVAC Applications**
  - Capacitive Type – dielectric constant of capacitor changes as moisture permeates through upper electrode; capacitance increases with increasing RH



Adapted from Yamatake

  - Resistive Type – ions are released as polymer coating absorbs moisture; resistance decreases with increasing relative humidity



Adapted from Yamatake

Relative Humidity Transmitters

- **Sensors from Six Manufacturers Tested: *Manufacturer / Type / NBCIP Cost* shown below**

Automation Components Inc.	- resistive	$125
Building Automation Products Inc.	- resistive	$150
General Eastern Inc.	- resistive	$194
Johnson Controls Inc.	- capacitive	$248
MAMAC Systems Inc.	- capacitive	$275
Vaisala	- capacitive	$180

Relative Humidity Transmitters

- **Testing Apparatus**
  - Thunder Scientific Model 2500 Two-Pressure Humidity Generator

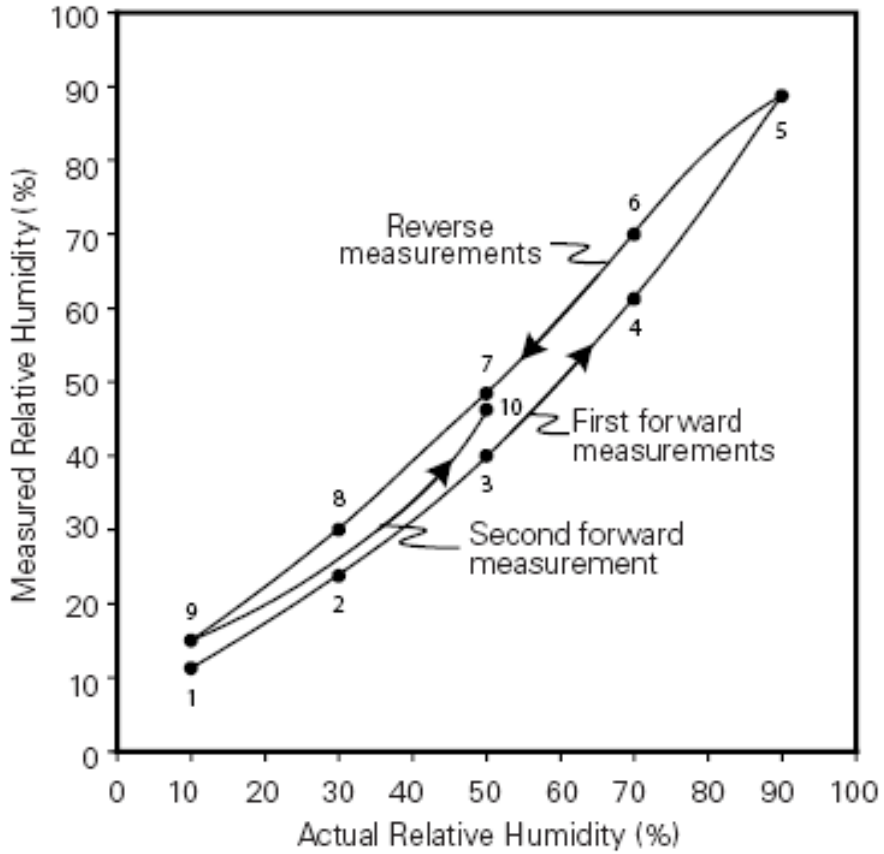
    ±0.5% RH accuracy
    from 10% – 98% RH
    and 32ºF – 158ºF

Courtesy Thunder Scientific

  - Laboratory grade power supply and data acquisition equipment

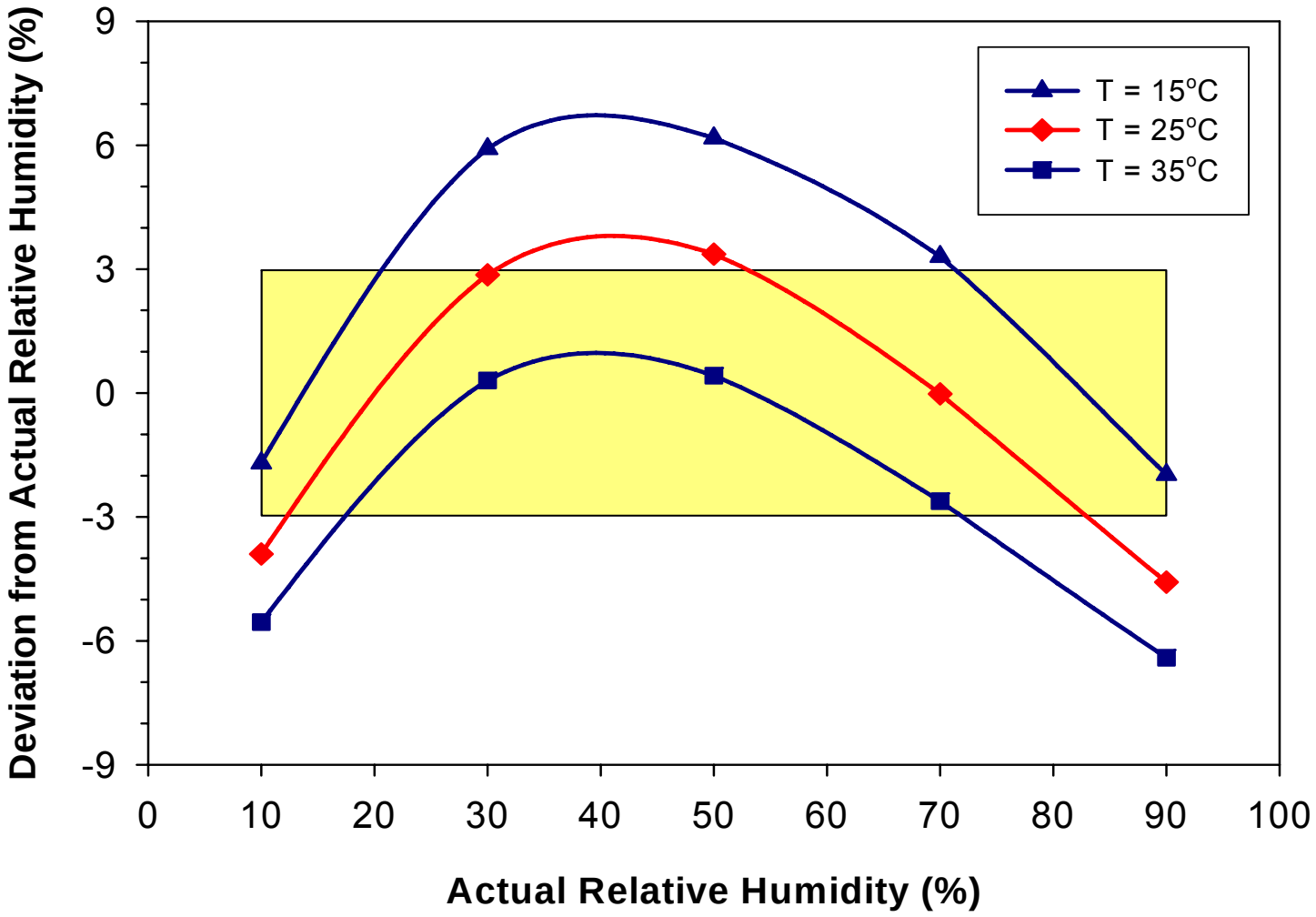
Relative Humidity Transmitters

- **Accuracy Testing of Newly Purchased Transmitters**



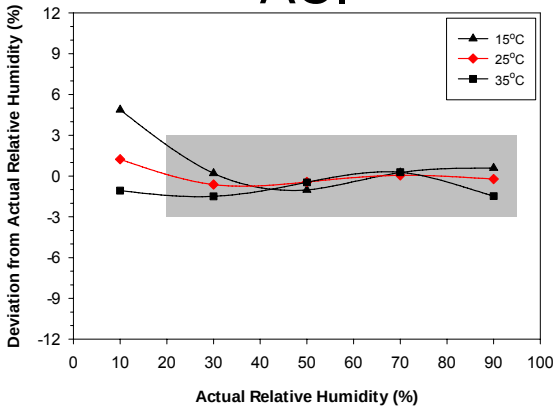
- 10, 30, 50, 70, and 90% RH
- 59°F, 77°F, and 95°F (15°C, 25°C, and 35°C)

Measured Accuracy Example

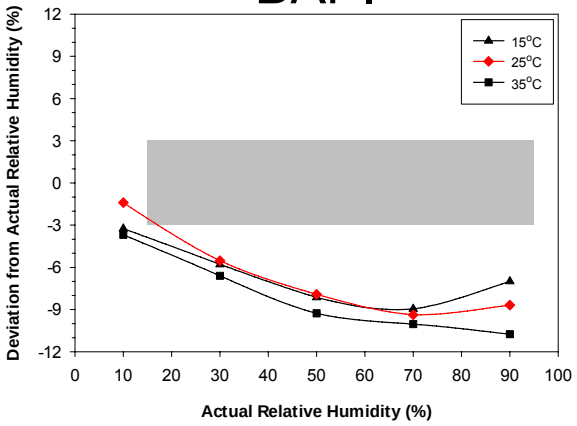


Measured Accuracy of New Transmitters

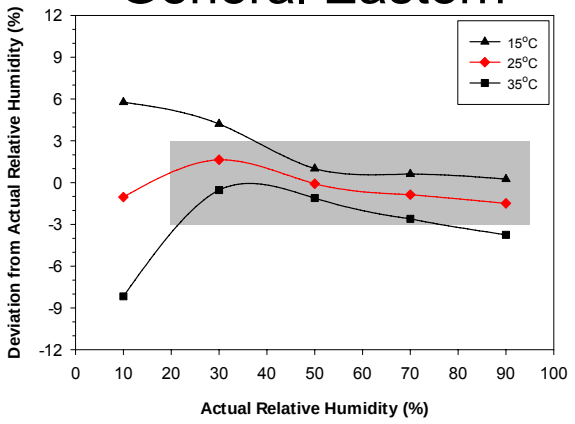
ACI



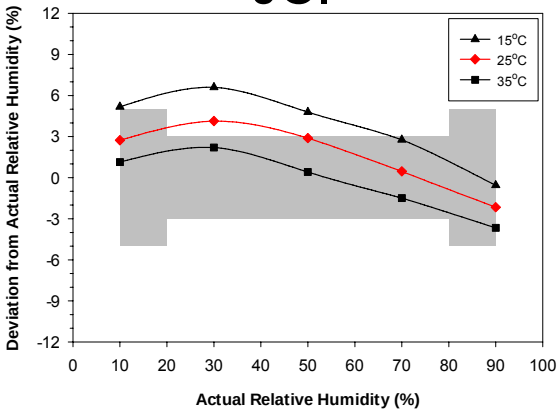
BAPI



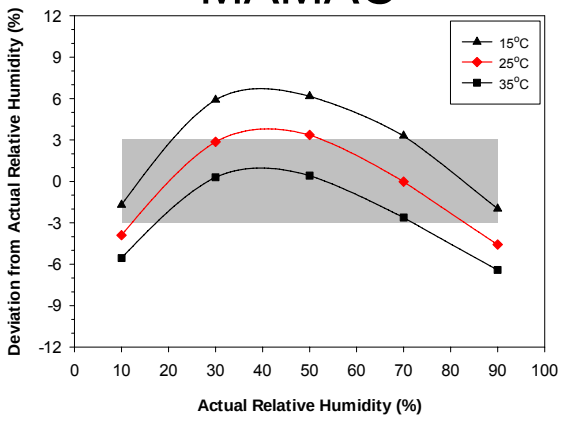
General Eastern



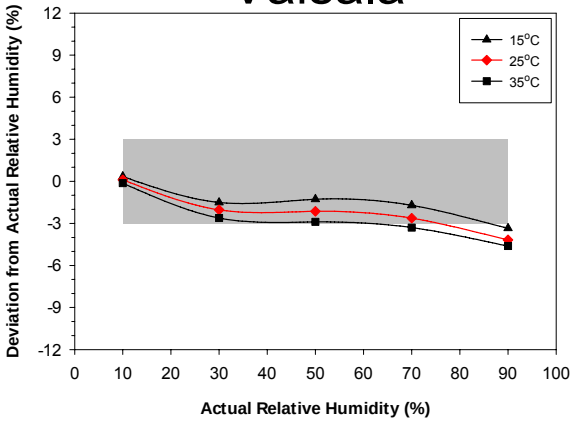
JCI



MAMAC



Vaisala

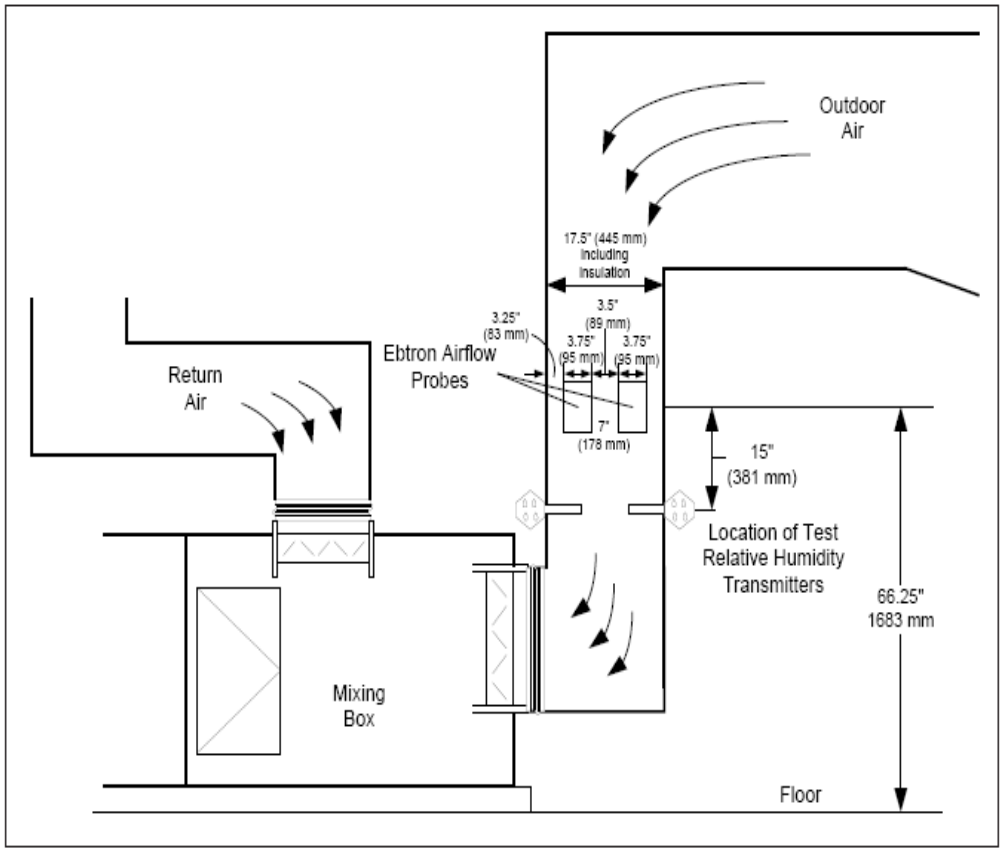


Relative Humidity Transmitters

- **Ageing Testing**
  - Purpose: Assess drift of RH transmitters exposed to typical HVAC environment
  - Best and worst performing sensor from each manufacturer selected for testing
  - Sensors installed in outdoor air duct at Energy Resource Station
  - Accuracy tested at 77ºF (25ºC) in Thunder Scientific humidity generator at four month intervals over one year

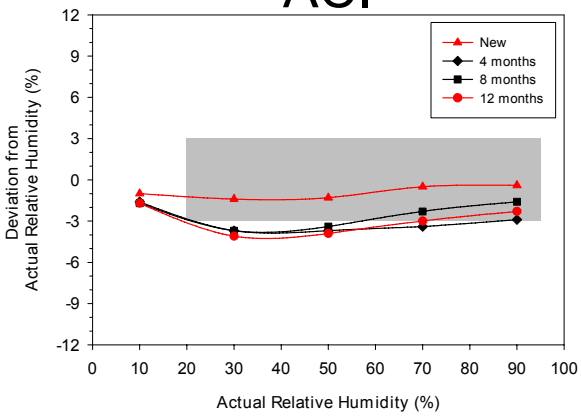
Relative Humidity Transmitters

- **Ageing Testing**

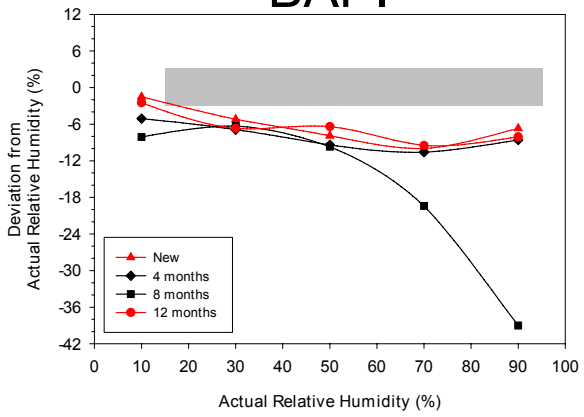


Accuracy at 77ºF After 1 Year of Ageing

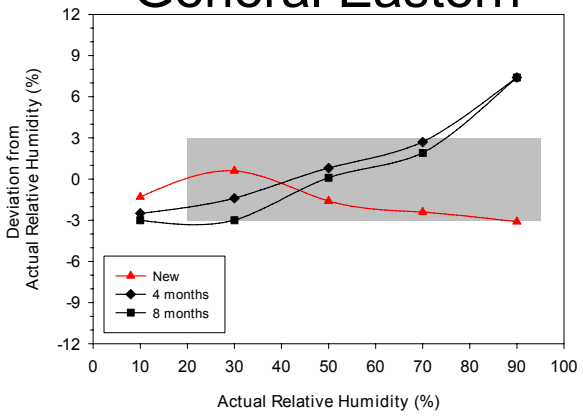
ACI



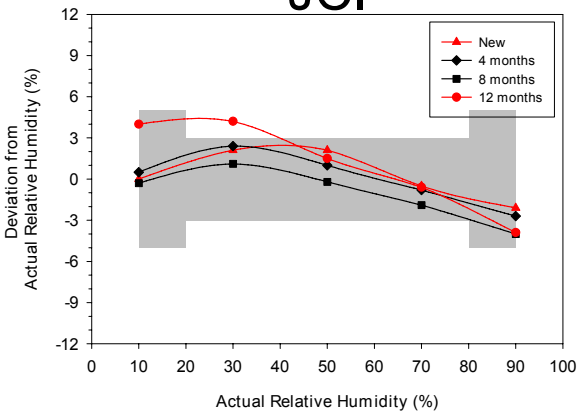
BAPI



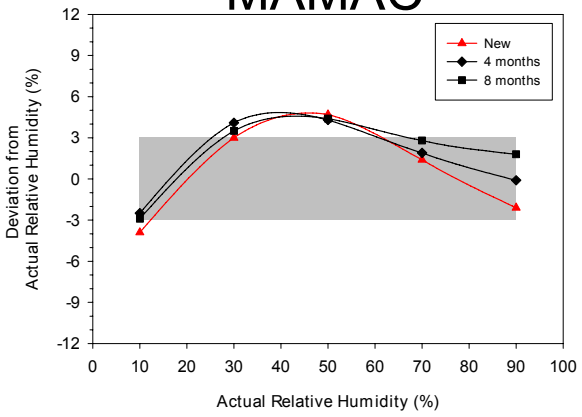
General Eastern



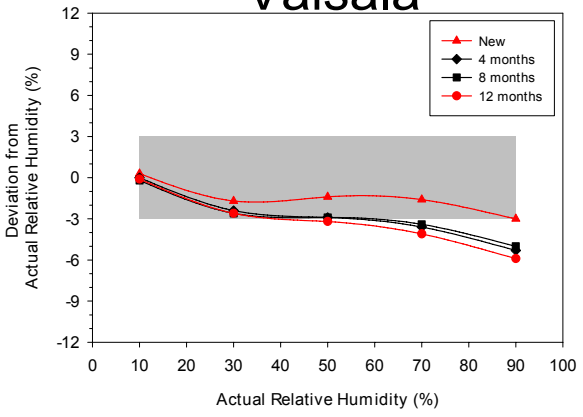
JCI



MAMAC

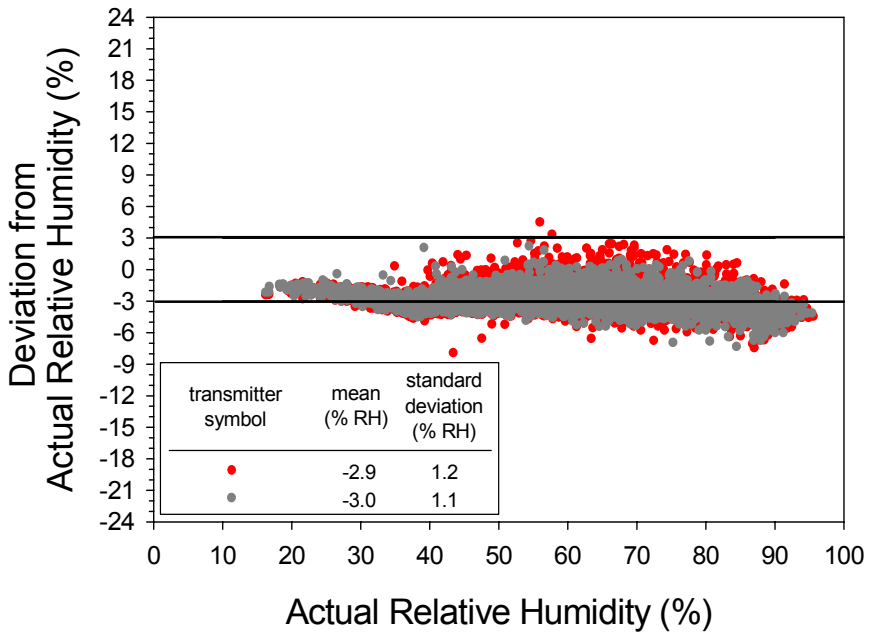


Vaisala

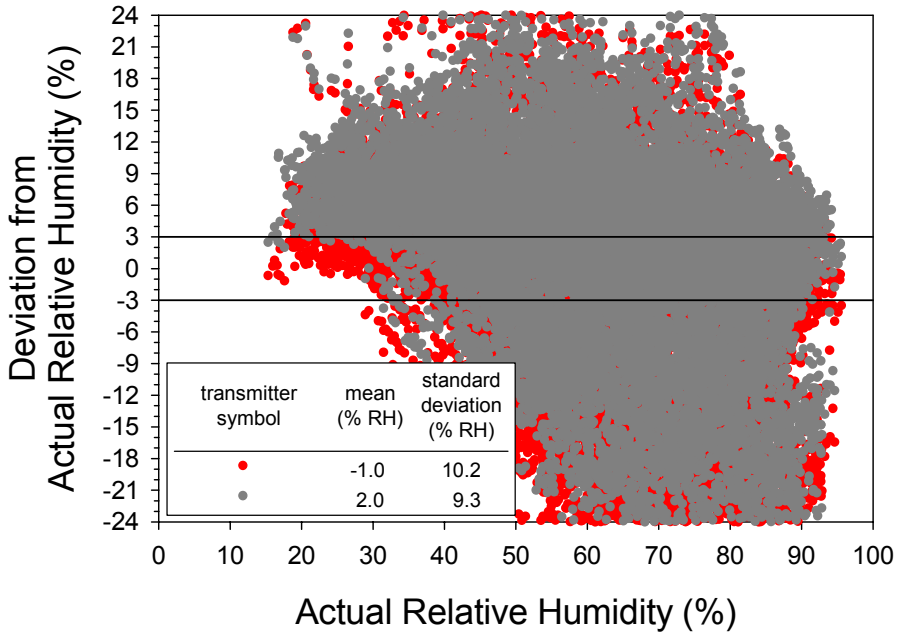


Aging / Drift Testing Results

Manufacturer X



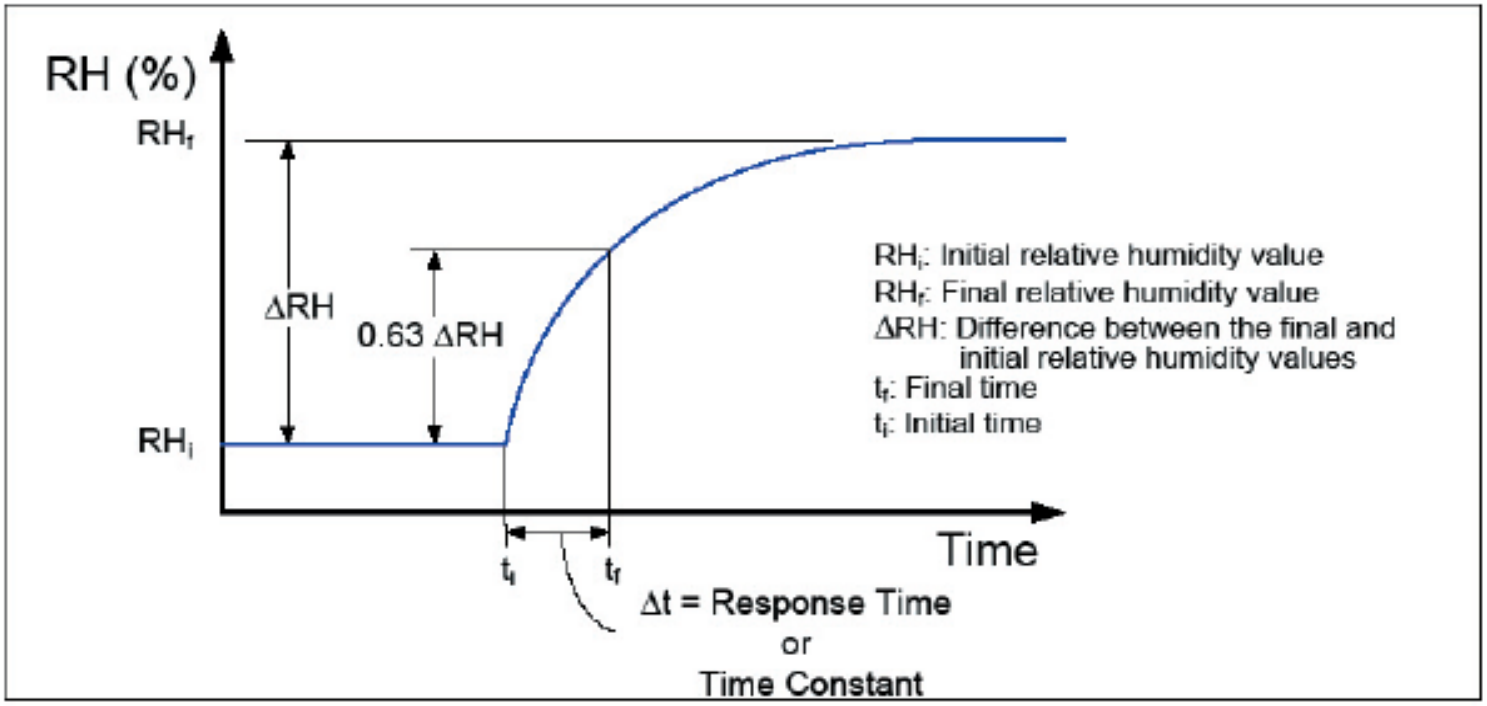
Manufacturer Y



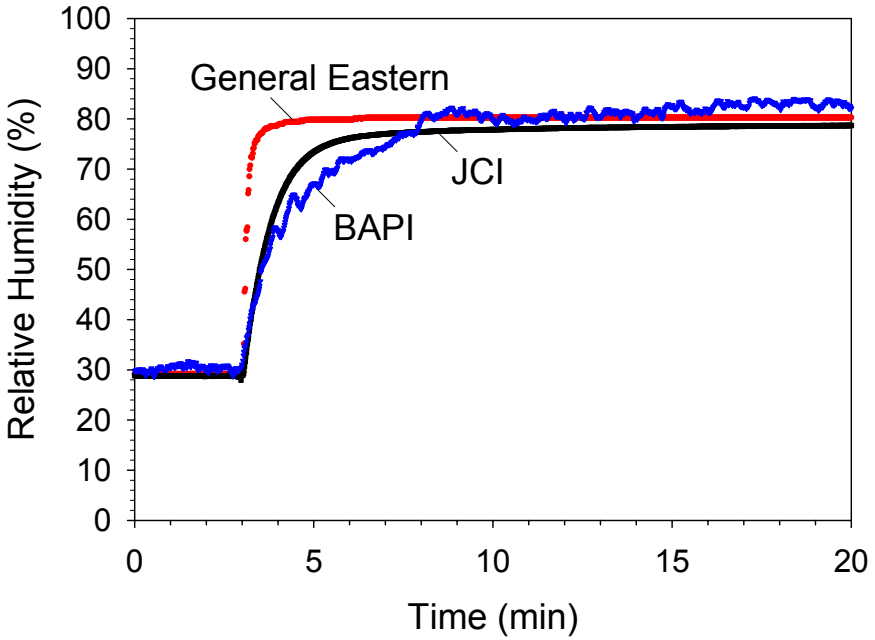
- One year of data collected at 15 minute intervals
- Filtered to eliminate data associated with velocities < 100 fpm
- Referee: Precision Grade ±1% RH in-situ reference sensor

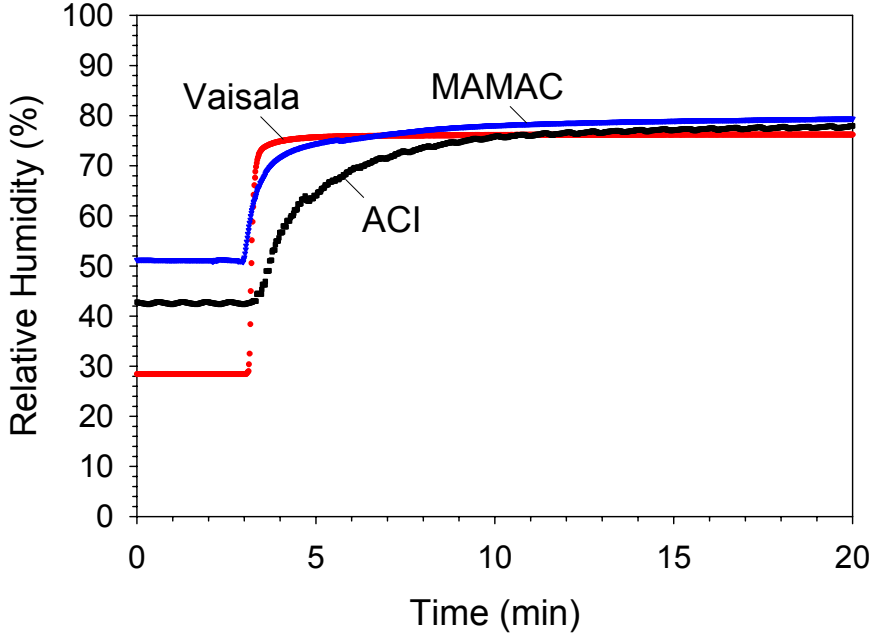
Relative Humidity Transmitters

- **Response Time Testing**
  - Approach: Measure the time required for the transmitters to respond to a step change in relative humidity



Response Time (or Time Constant)





- General Eastern and Vaisala: time constant ~ 10 s
- JCI and MAMAC: time constant ~ 50 to 60 s
- BAPI and ACI: time constant ~ 90 s

Relative Humidity Transmitters

- **Stress Testing**
  - Purpose: Assess robustness of RH transmitters exposed to harsh environments
    - Cycling
    - Desiccation-Saturation
    - Submergence

Relative Humidity Transmitters

- **Stress Testing**
  - Cycling
    - 50 cycles from 10% to 95% RH in Thunder Scientific humidity generator at 41ºF and 95ºF
    - One cycle per hour
    - Accuracy tested at 77ºF (25ºC) in Thunder Scientific humidity generator after testing

Relative Humidity Transmitters

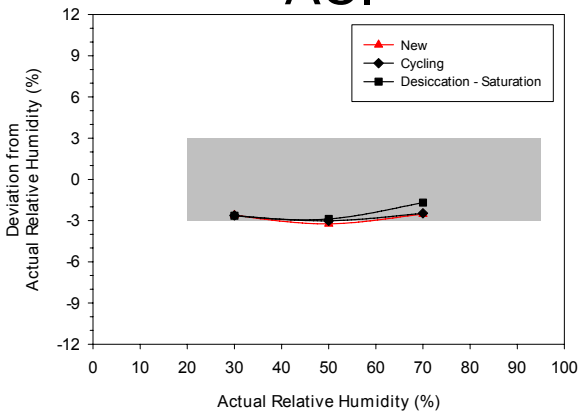
- **Stress Testing**
  - Desiccation-Saturation
    - RH sensors exposed to 0% RH environment for two days
    - RH sensors exposed to 100% RH environment for two days
    - Accuracy tested at 77ºF (25ºC) in Thunder Scientific humidity generator after each phase of testing

Relative Humidity Transmitters

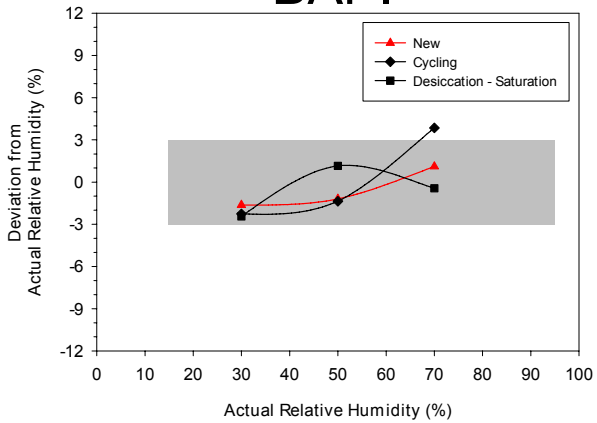
- **Stress Testing**
  - Submersion
    - RH sensors submerged for one day
    - Accuracy tested at 77ºF (25ºC) in Thunder Scientific humidity generator
    - RH sensors allowed to dry out for one day
    - Accuracy retested at 77ºF (25ºC) in Thunder Scientific humidity generator

Accuracy after Stress Tests

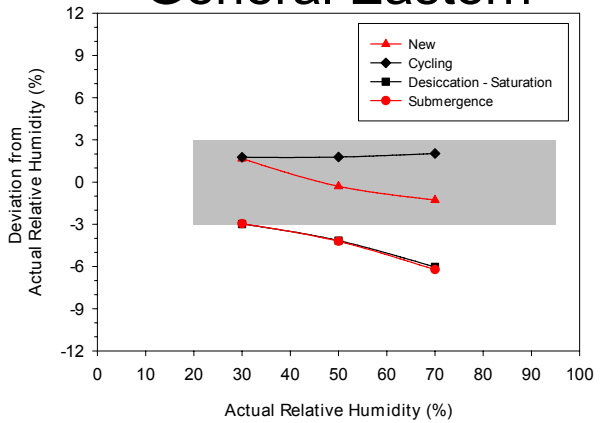
ACI



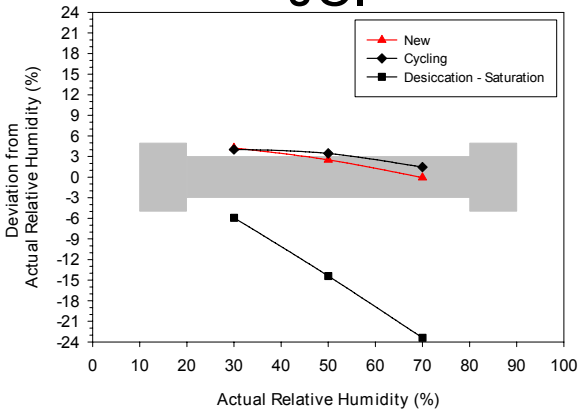
BAPI



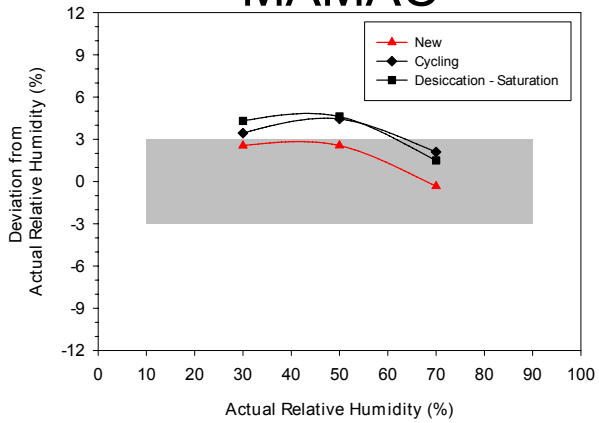
General Eastern



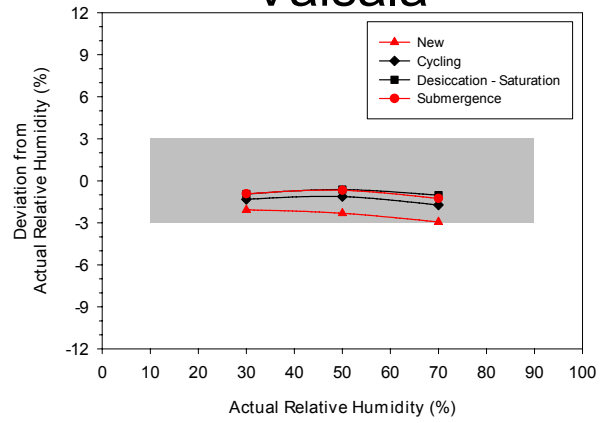
JCI



MAMAC



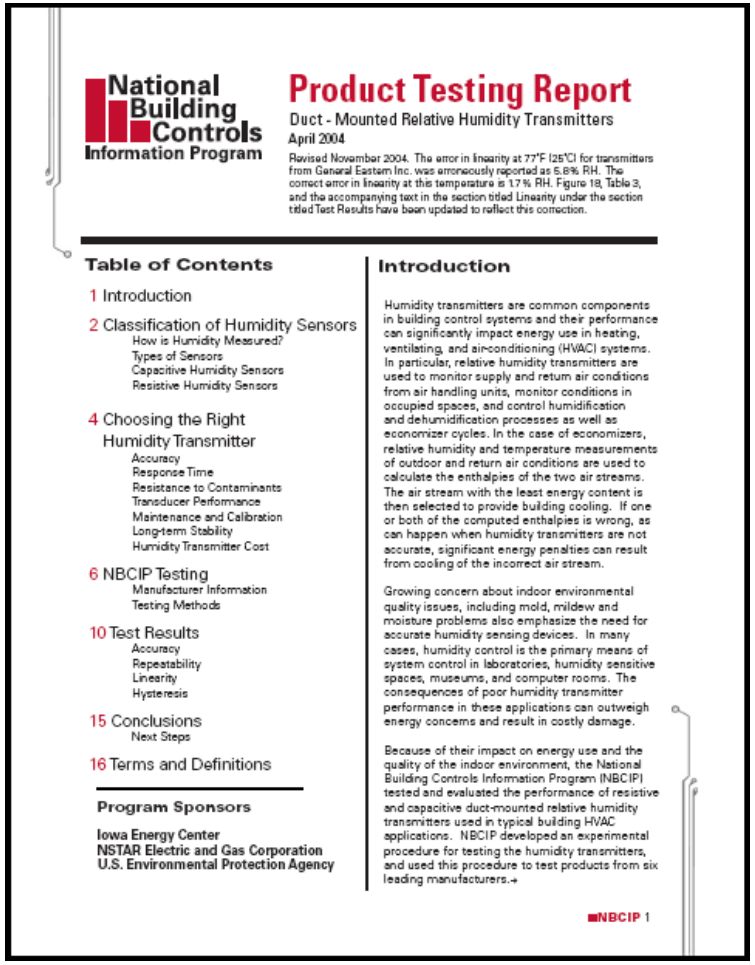
Vaisala



Relative Humidity Transmitters

- **Summary of Findings**
  - Numerous transmitters failed during the ageing and stress tests; only Vaisala had 0 failed transmitters
  - Incompatibility found between the BAPI transmitter and the JCI DX-9100 controller used for in-situ data logging – custom configuration necessary
  - Despite claims, no common pattern of variation observed between capacitive and resistive type sensors
  - Significant deviations between sensors noted during installed performance aging tests
  - Cost is not a reliable indicator of performance

Relative Humidity Transmitters



National Building Controls Information Program

Product Testing Report

Duct - Mounted Relative Humidity Transmitters

April 2004

Revised November 2004. The error in linearity at 77°F [25°C] for transmitters from General Eastern Inc. was erroneously reported as 5.8% RH. The correct error in linearity at this temperature is 1.7 % RH. Figure 18, Table 3, and the accompanying text in the section titled Linearity under the section titled Test Results have been updated to reflect this correction.

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Program Sponsors

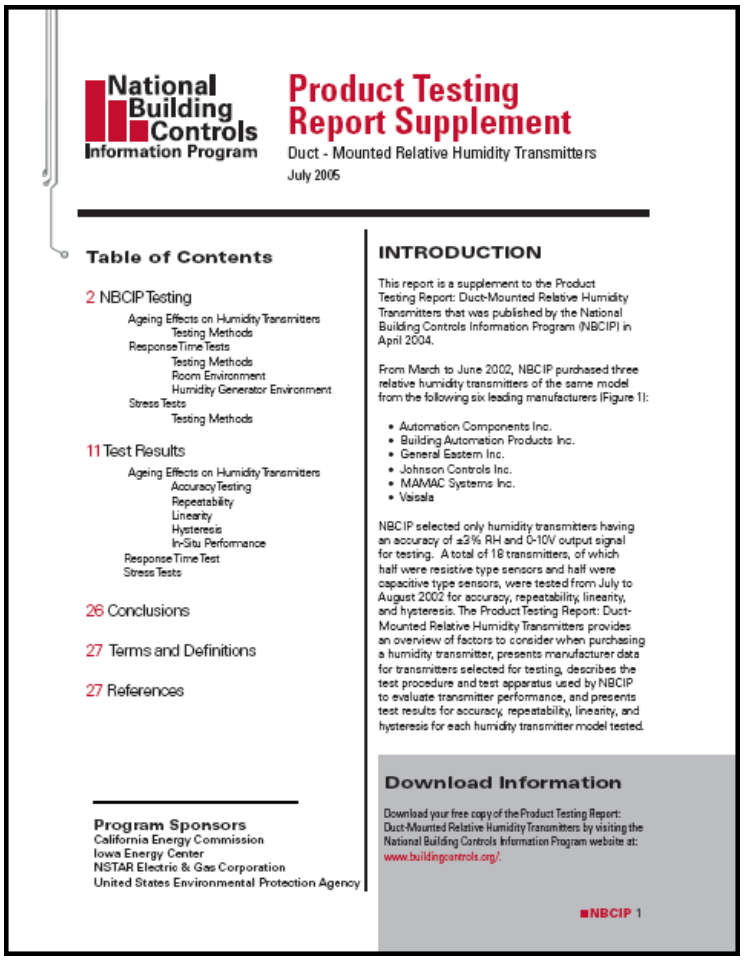
Iowa Energy Center
NSTAR Electric and Gas Corporation
U.S. Environmental Protection Agency

Introduction

Humidity transmitters are common components in building control systems and their performance can significantly impact energy use in heating, ventilating, and air-conditioning (HVAC) systems. In particular, relative humidity transmitters are used to monitor supply and return air conditions from air handling units, monitor conditions in occupied spaces, and control humidification and dehumidification processes as well as economizer cycles. In the case of economizers, relative humidity and temperature measurements of outdoor and return air conditions are used to calculate the enthalpies of the two air streams. The air stream with the least energy content is then selected to provide building cooling. If one or both of the computed enthalpies is wrong, as can happen when humidity transmitters are not accurate, significant energy penalties can result from cooling of the incorrect air stream.

Growing concern about indoor environmental quality issues, including mold, mildew and moisture problems also emphasize the need for accurate humidity sensing devices. In many cases, humidity control is the primary means of system control in laboratories, humidity sensitive spaces, museums, and computer rooms. The consequences of poor humidity transmitter performance in these applications can outweigh energy concerns and result in costly damage.

Because of their impact on energy use and the quality of the indoor environment, the National Building Controls Information Program (NBCIP) tested and evaluated the performance of resistive and capacitive duct-mounted relative humidity transmitters used in typical building HVAC applications. NBCIP developed an experimental procedure for testing the humidity transmitters, and used this procedure to test products from six leading manufacturers.→



National Building Controls Information Program

Product Testing Report Supplement

Duct - Mounted Relative Humidity Transmitters

July 2005

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Program Sponsors

California Energy Commission
Iowa Energy Center
NSTAR Electric & Gas Corporation
United States Environmental Protection Agency

INTRODUCTION

This report is a supplement to the Product Testing Report: Duct-Mounted Relative Humidity Transmitters that was published by the National Building Controls Information Program (NBCIP) in April 2004.

From March to June 2002, NBCIP purchased three relative humidity transmitters of the same model from the following six leading manufacturers (Figure 1):

- Automation Components Inc.
- Building Automation Products Inc.
- General Eastern Inc.
- Johnson Controls Inc.
- MAMAC Systems Inc.
- Vaisala

NBCIP selected only humidity transmitters having an accuracy of ±3% RH and 0-10V output signal for testing. A total of 18 transmitters, of which half were resistive type sensors and half were capacitive type sensors, were tested from July to August 2002 for accuracy, repeatability, linearity, and hysteresis. The Product Testing Report: Duct-Mounted Relative Humidity Transmitters provides an overview of factors to consider when purchasing a humidity transmitter, presents manufacturer data for transmitters selected for testing, describes the test procedure and test apparatus used by NBCIP to evaluate transmitter performance, and presents test results for accuracy, repeatability, linearity, and hysteresis for each humidity transmitter model tested.

Download Information

Download your free copy of the Product Testing Report: Duct-Mounted Relative Humidity Transmitters by visiting the National Building Controls Information Program website at: www.buildingcontrols.org/.

- **Reports – available free at www.buildingcontrols.org**

NBCIP

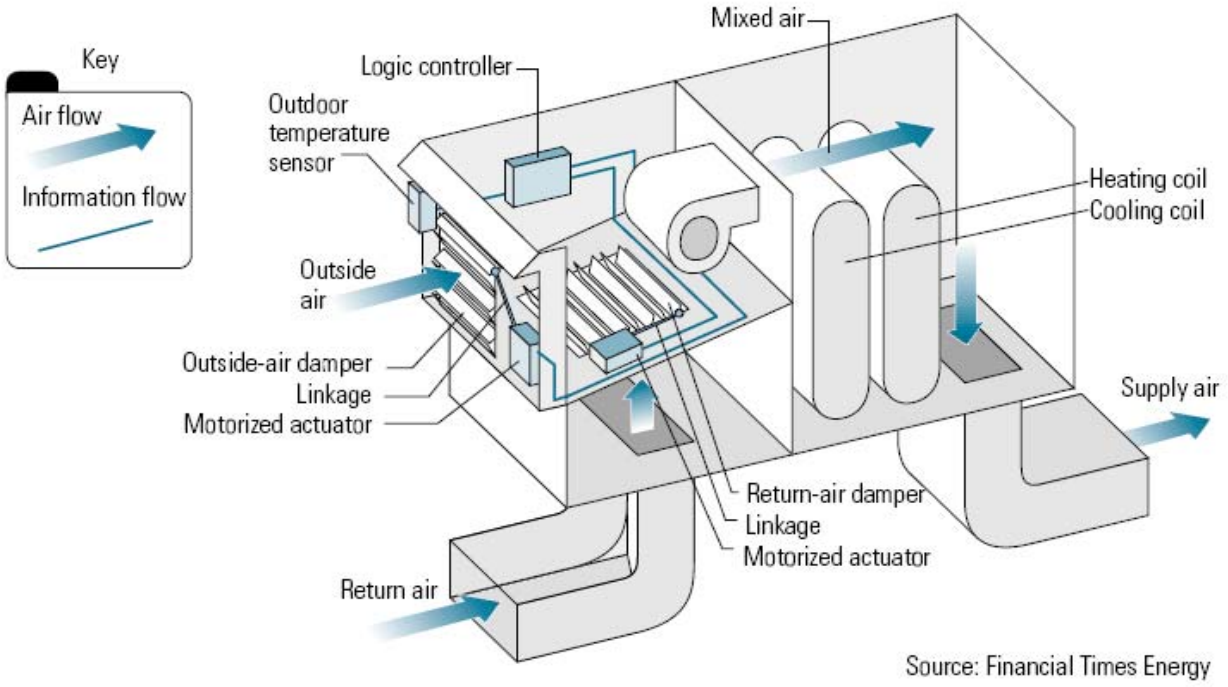
Part 2: Economizer Sensors

- **ASHRAE 90.1 and CEC Title 24 Requirements**
- **Economizer Control Types**
- **Economizer Sensor Testing**
- **Pretest Results**

National Building Controls Information Program

Background

- **What Is An Economizer?**
  - A system of sensors, dampers, actuators and logic devices arranged to use outside air under the appropriate conditions to provide cooling to the conditioned space



Background

- **Basic Economizer Control Functions**
  - Economizer Enable Logic:
    - Sensors measure Outside Air (and Return Air) conditions.
    - Logic device determines that it is advantageous to use outside air for cooling and enables the damper control process
  - Damper Control Process:
    - Modulates the Outside and Return Air dampers to maintain a setpoint – typically mixed air or supply air temperature
    - Variations control Relief/Exhaust Air dampers and/or Mechanical Cooling in conjunction with the outside air damper to effect improved control and reduced cooling energy

Background

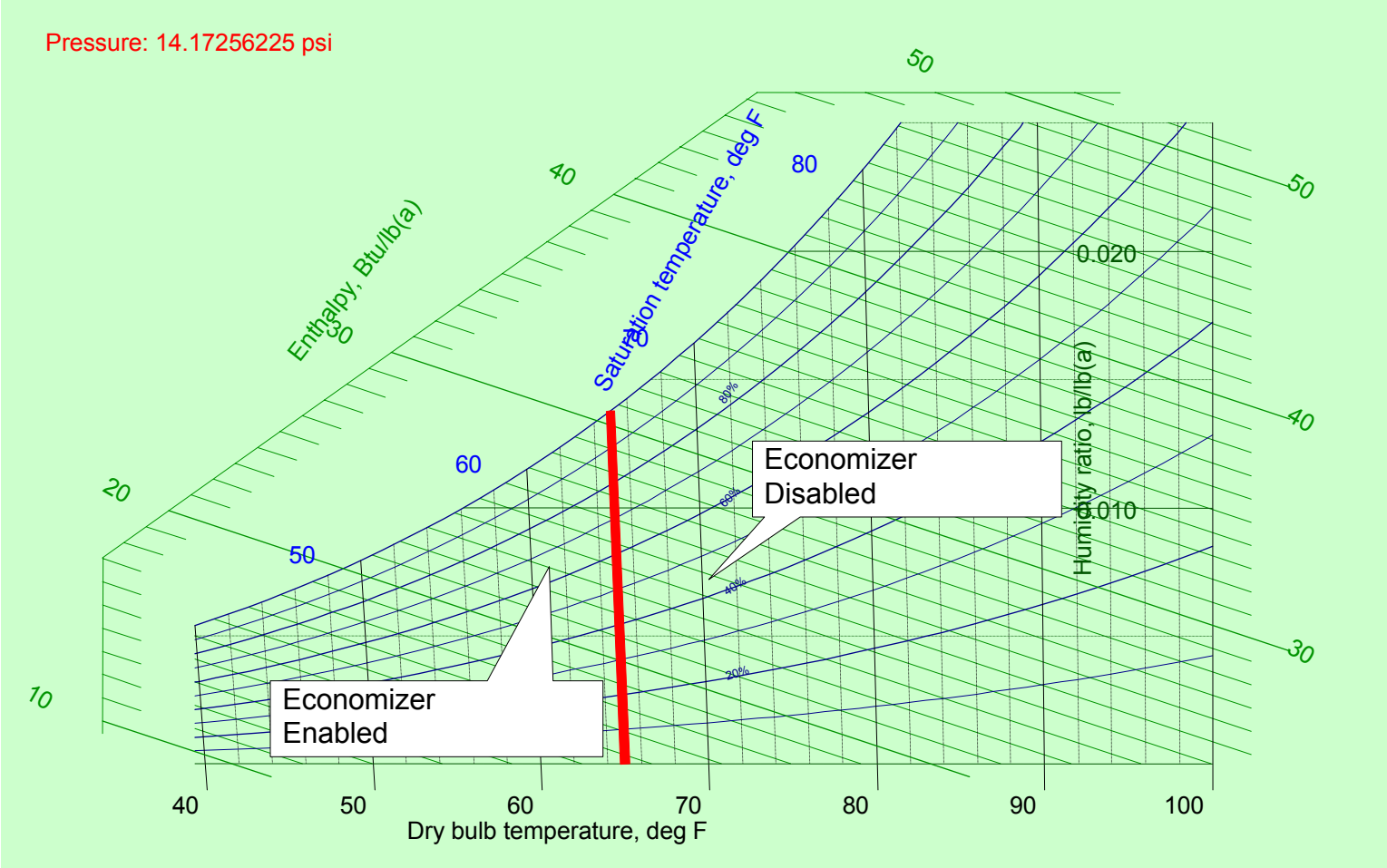
- **Economizer Enable Logic**

Strategy	Conditions to Enable Economizer
Fixed Dry Bulb	OA temp is less than controller setpoint
Fixed Enthalpy	OA enthalpy is less than controller setpoint
Differential Dry Bulb	OA temp is less than RA temp
Differential Enthalpy	OA enthalpy is less than RA enthalpy

- **Economizer Evolution**
  - 1950's – Fixed Temperature Based
  - 1970's – Nylon Element Electromechanical Enthalpy Sensor Based
  - 1980's – Solid State Enthalpy Sensor Based
  - 1990's – DDC Controller w/ Psychrometric Logic Based

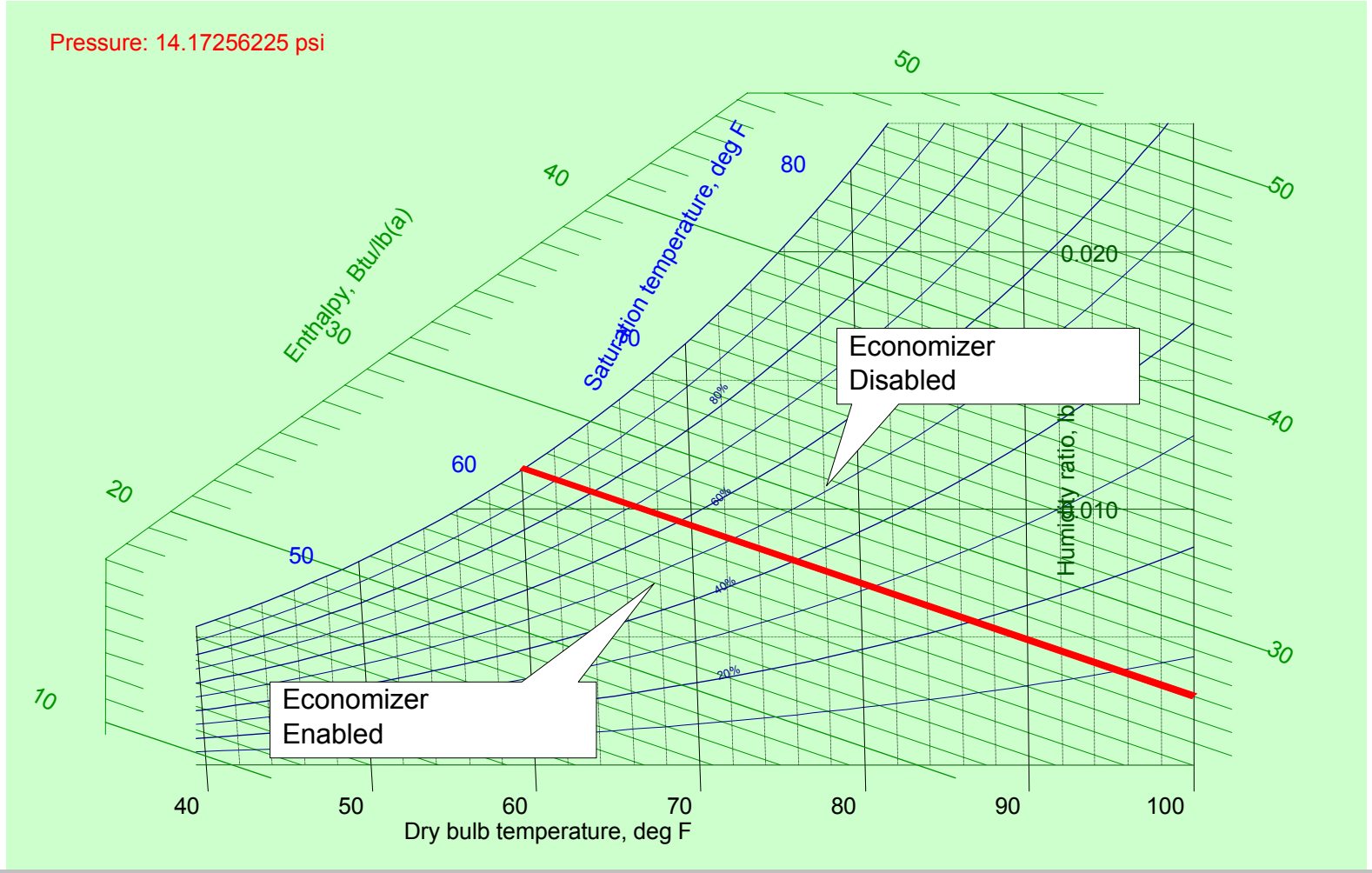
Background

- **Control Strategy – Fixed Dry Bulb Switchover**



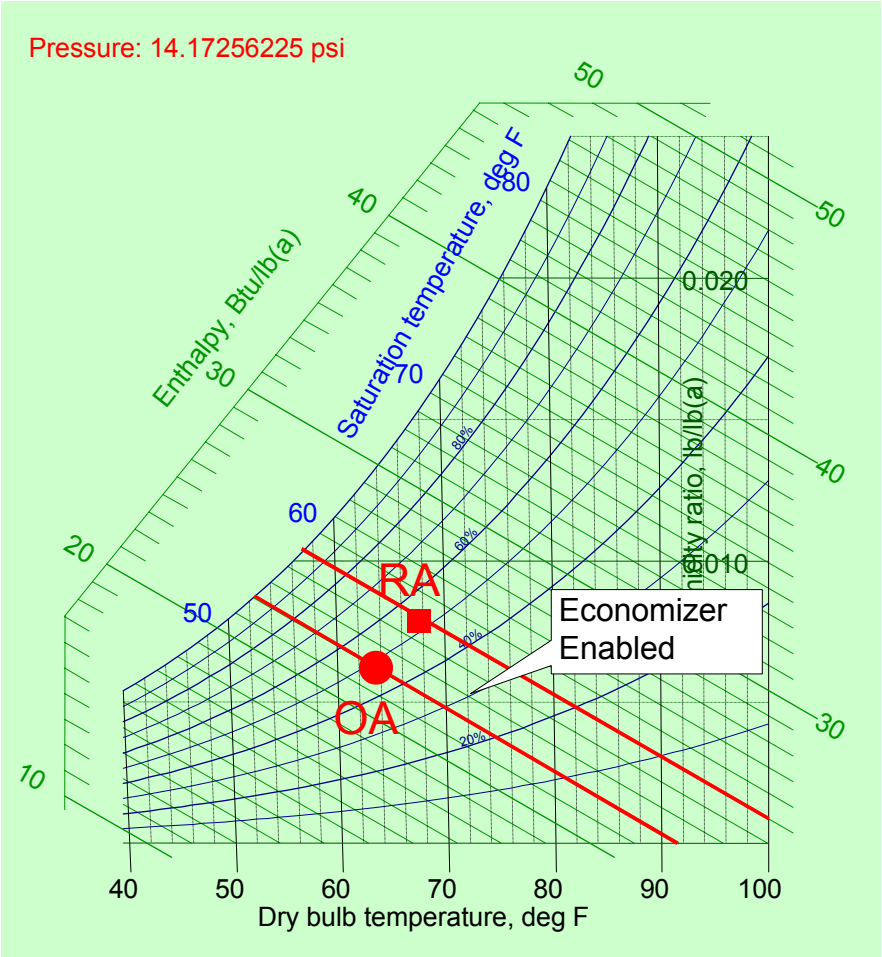
Background

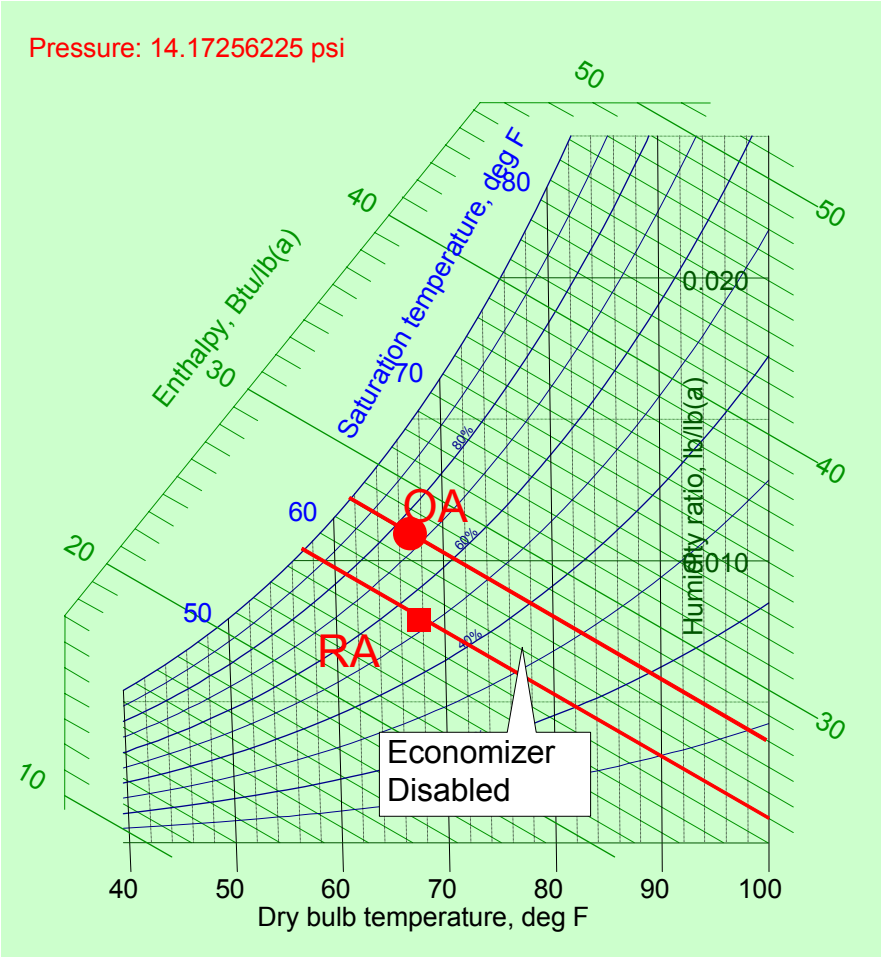
- **Control Strategy – Fixed Enthalpy Switchover**



Background

- **Control Strategy – Differential Enthalpy Switchover**





ASHRAE 90.1 Requirements

- **Each cooling system having a fan shall include either an air or water economizer**
- **Exceptions:**
  - Small Individual Fan Coil Units in defined climate zones
  - High OA with process humidification
  - Condenser heat recovery
  - Residential spaces
  - Low use spaces (> 20 hours per week)
  - Other exceptions

CEC Title 24 Requirements

- **Each individual cooling fan system that has a design supply capacity over 2,500 CFM and a total mechanical cooling capacity over 75,000 Btu/hr shall include either:**
  - An air economizer capable of modulating outside-air and return-air dampers to supply 100 percent of the design supply air quantity as outside-air; or
  - A water economizer capable of providing 100 percent of the expected system cooling load as calculated in accordance with a method approved by the commission, at outside air temperatures of 50°F dry-bulb/45°F wet-bulb and below.
- **Five Listed Exceptions**
- **Economizer shall not increase building heating energy use**
- **Provide partial cooling to supplement mechanical cooling**

CEC Title 24 Requirements

- **Air-side economizers shall have high limit shutoff controls complying with TABLE 144-C**

TABLE 144-C AIR ECONOMIZER HIGH LIMIT SHUT OFF CONTROL REQUIREMENTS

Device Type	Climate Zones	Required High Limit (Economizer Off When):	
		Equation	Description
Fixed Dry Bulb	1, 2, 3, 5, 11, 13, 14, 15 & 16	$T_{OA} > 75°F$	Outside air temperature exceeds 75°F
	4, 6, 7, 8, 9, 10 & 12	$T_{OA} > 70°F$	Outside air temperature exceeds 70°F
Differential Dry Bulb	All	$T_{OA} > T_{RA}$	Outside air temperature exceeds return air temperature
Fixed Enthalpy[a]	4, 6, 7, 8, 9, 10 & 12	$h_{OA} > 28$ Btu/lb[b]	Outside air enthalpy exceeds 28 Btu/lb of dry air[b]
Electronic Enthalpy	All	$(T_{OA}, RH_{OA}) > A$	Outside air temperature/RH exceeds the "A" set-point curve[c]
Differential Enthalpy	All	$h_{OA} > h_{RA}$	Outside air enthalpy exceeds return air enthalpy

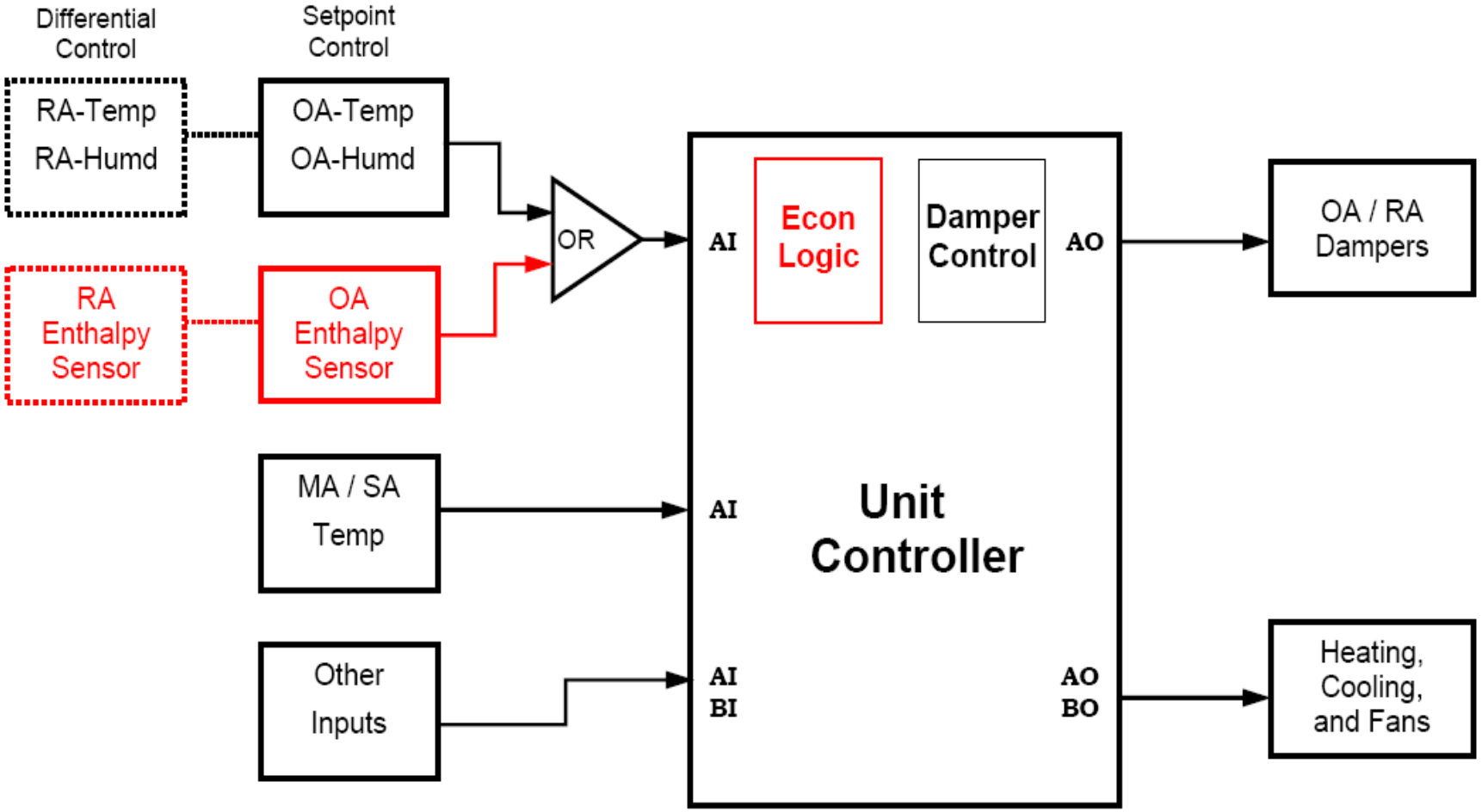
[a] Fixed Enthalpy Controls are prohibited in climate zones 1, 2, 3, 5, 11, 13, 14, 15 & 16.

[b] At altitudes substantially different than sea level, the Fixed Enthalpy limit value shall be set to the enthalpy value at 75°F and 50% relative humidity. As an example, at approximately 6000 foot elevation the fixed enthalpy limit is approximately 30.7 Btu/lb.

[c] Set point "A" corresponds to a curve on the psychometric chart that goes through a point at approximately 75°F and 40% relative humidity and is nearly parallel to dry bulb lines at low humidity levels and nearly parallel to enthalpy lines at high humidity levels.

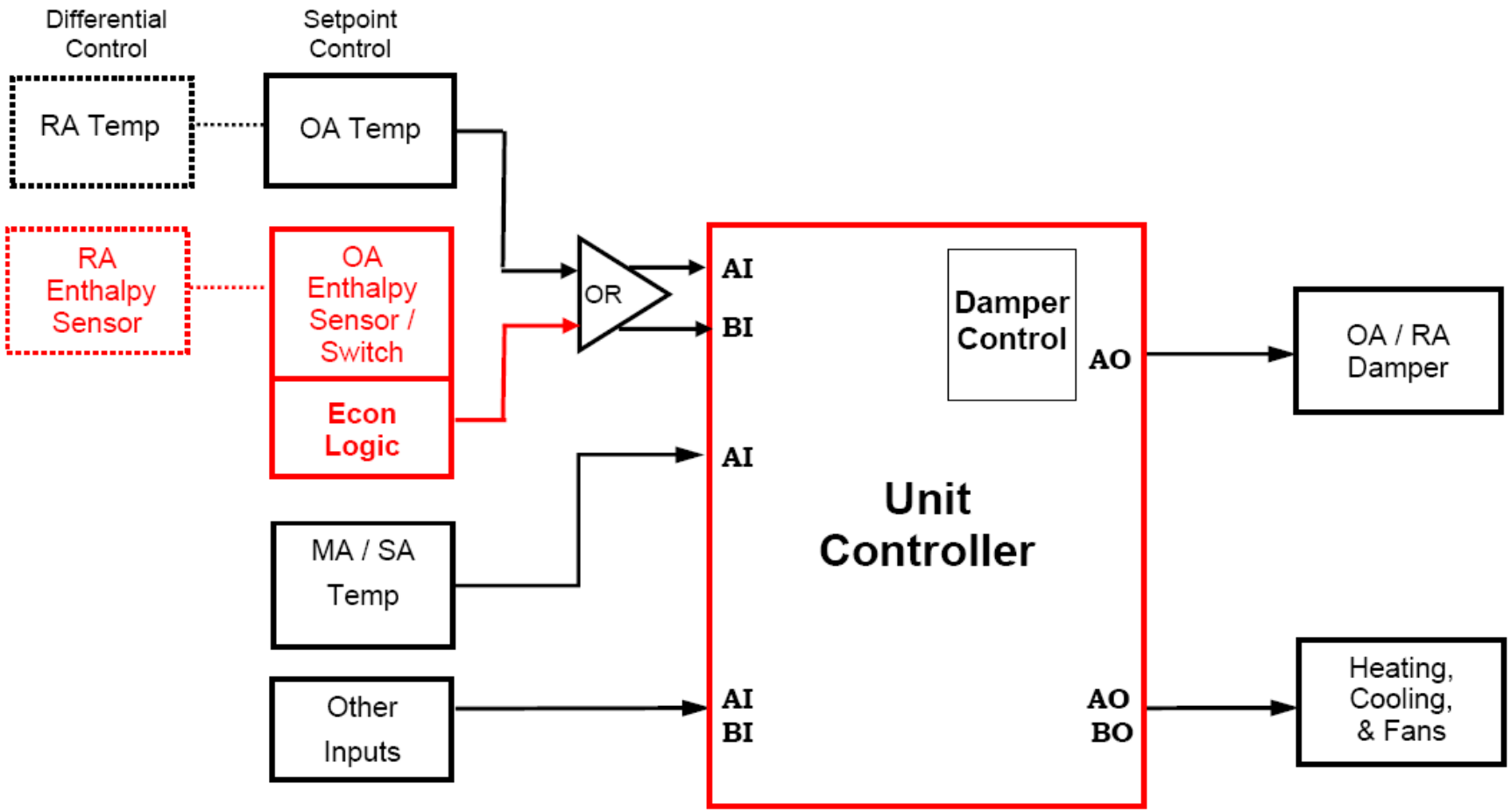
Economizer Control Types

- **Type 1- Fully Integrated through Unit Controller**



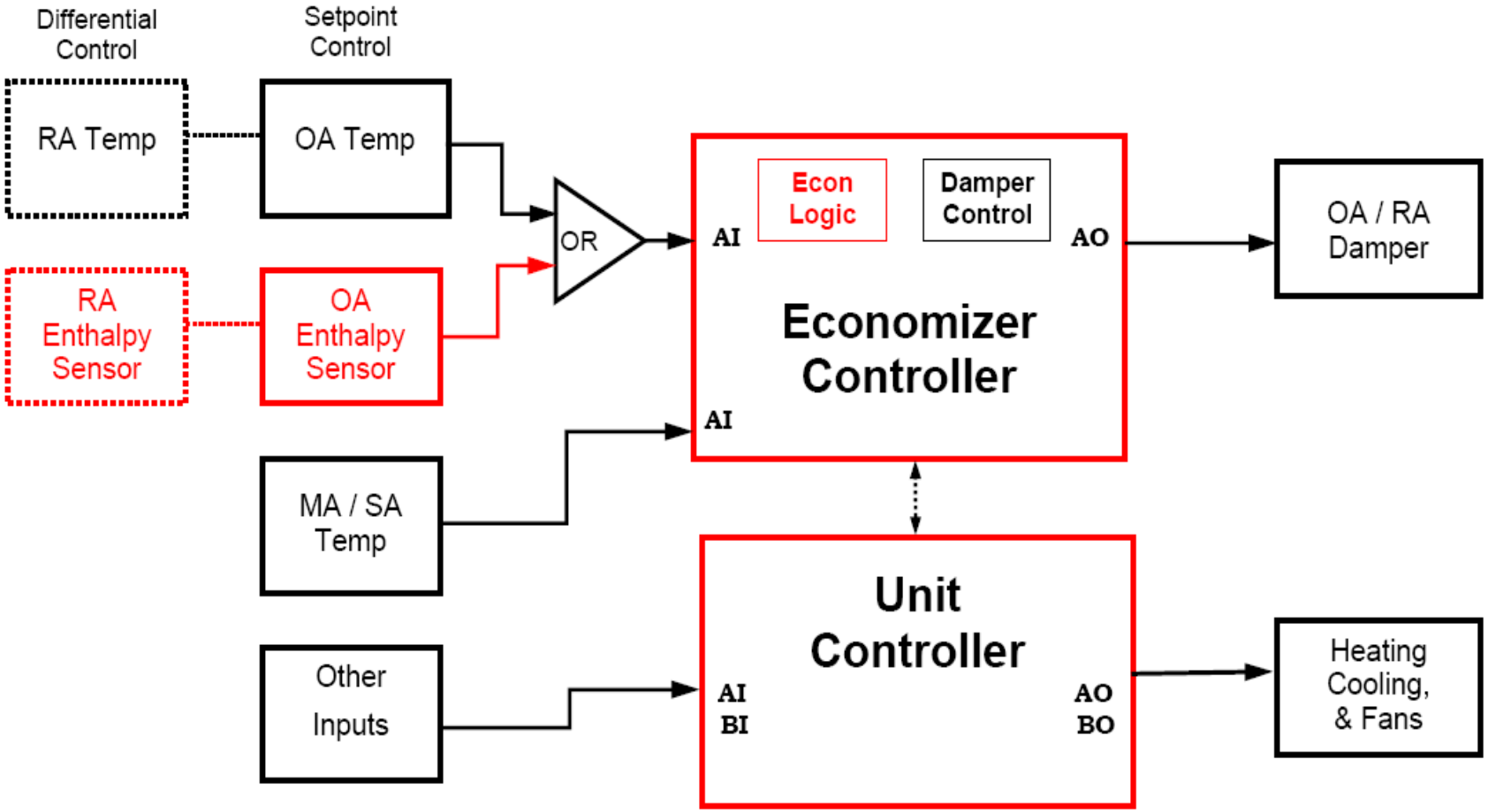
Economizer Control Types

- **Type 2 – Partially Integrated**



Economizer Control Types

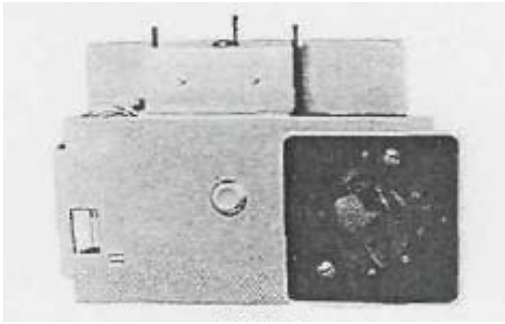
- **Type 3 – Segregated w/ package Economizer Controller**



Economizer Control Devices

Discharge Air Temp Sensor

Damper Actuator



Electro-Mechanical
Enthalpy Switch

Mixed Air Temp Sensor

Solid State
Economizer
Logic
Module

Enthalpy or Temperature
Sensor

Solid State Economizer
Logic Module

Enthalpy Sensor

Economizer Sensor Testing

- **Why Test Them?**
  - Sensors enable and control system Outside Air
  - Significant energy penalty and IAQ impact
  - Many field performance problems noted

- **Devices Under Test – (Enthalpy Based)**

Device	Manufacturer	Model	Avg. Cost
Enthalpy Sensor	Honeywell	C7400A1004	$ 46
	ACI	ACI/ENT	$ 82
Enthalpy Switch	Honeywell	H205A1038	$ 332
		H705A1003	$ 109
	ACI	ACI/DIFF-ENT	$ 88
	TAC/Invensys	THC-2	$ 139

Economizer Sensor Testing

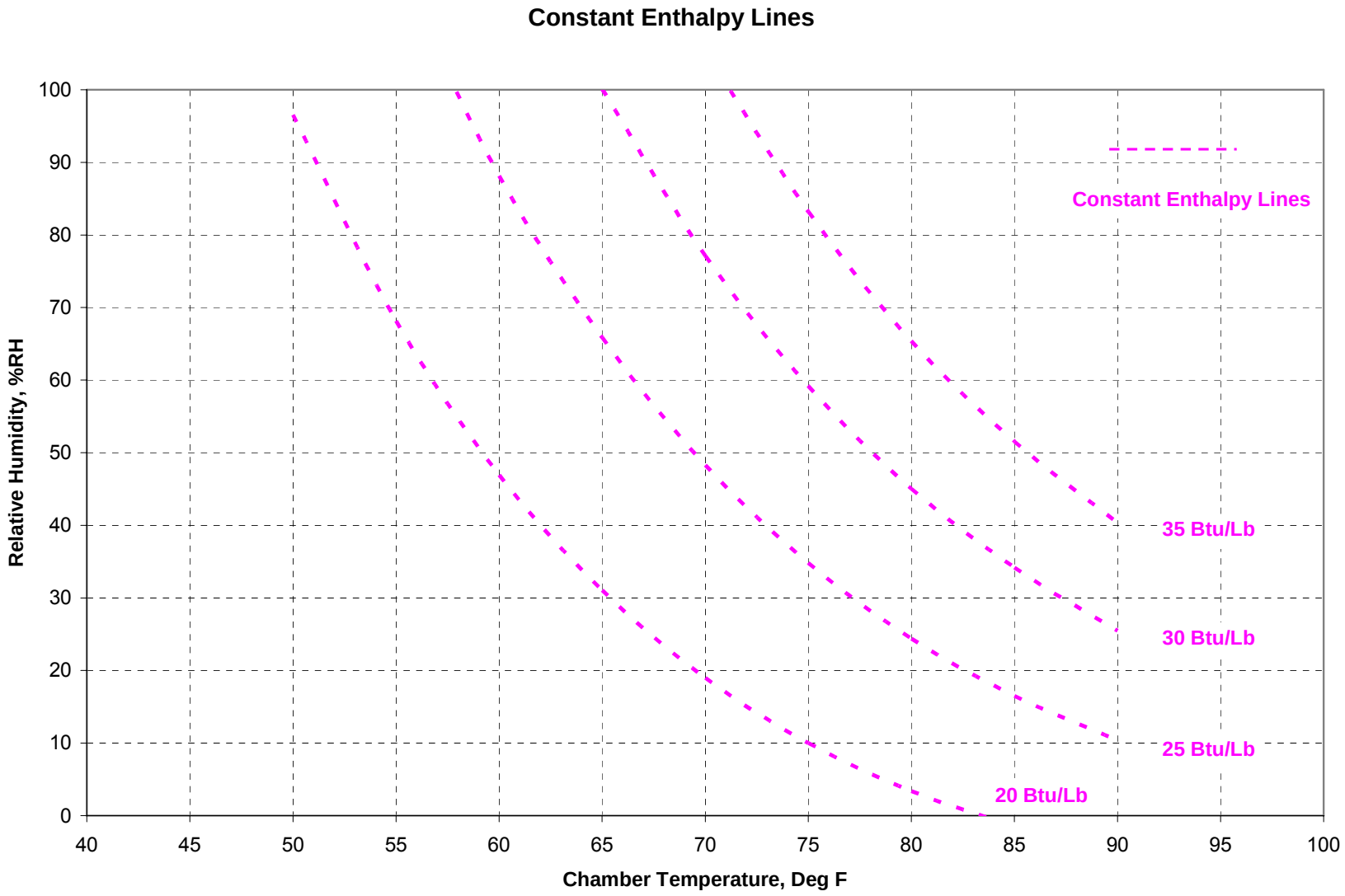
- **Testing Apparatus**
  - Thunder Scientific Model 2500 Two-Pressure Humidity Generator

    ±0.5% RH accuracy
    from 10% – 98% RH
    and 32ºF – 158ºF

Courtesy Thunder Scientific

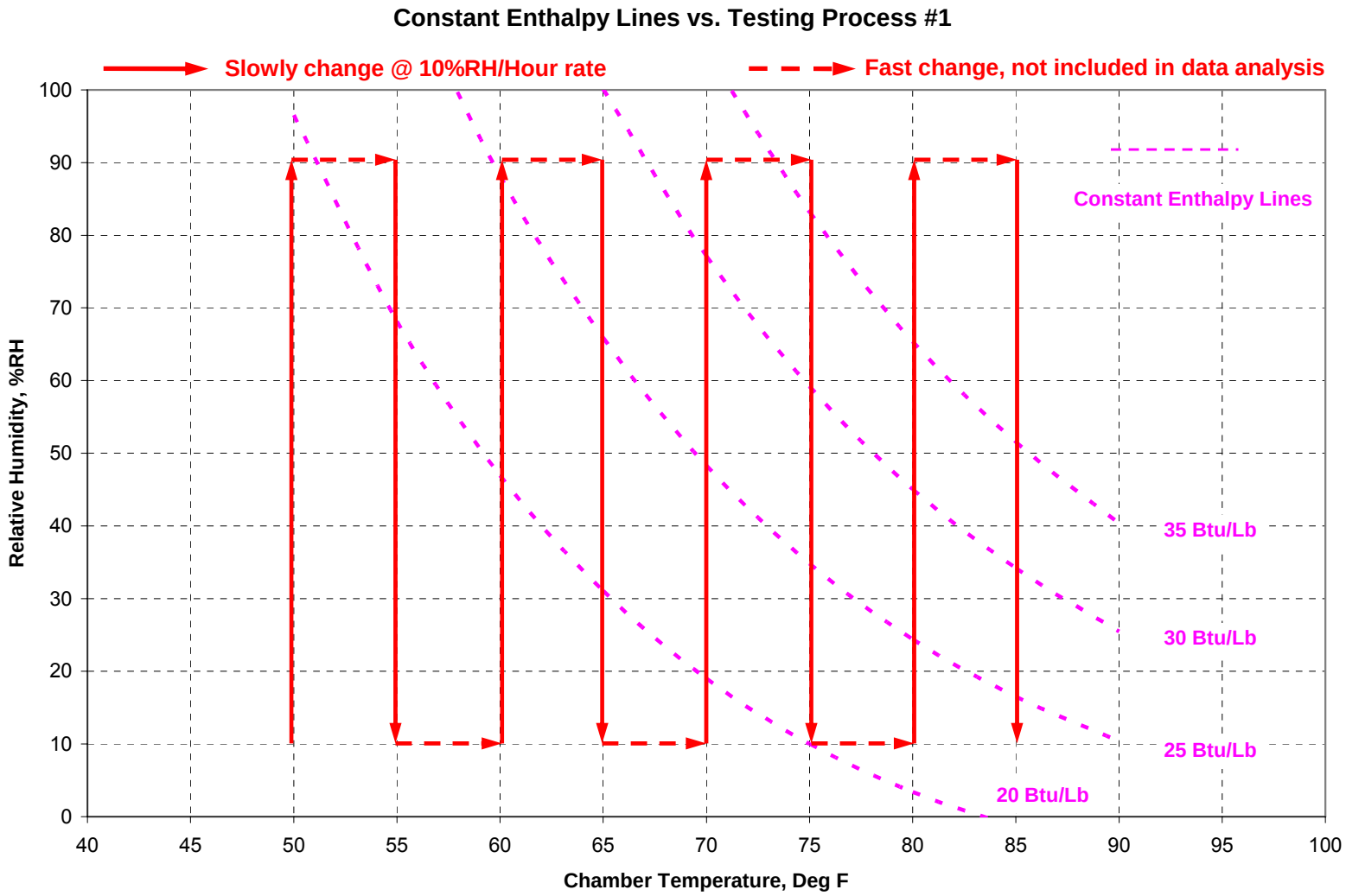
  - Laboratory grade power supply and data acquisition equipment

Economizer Sensor Test Procedure



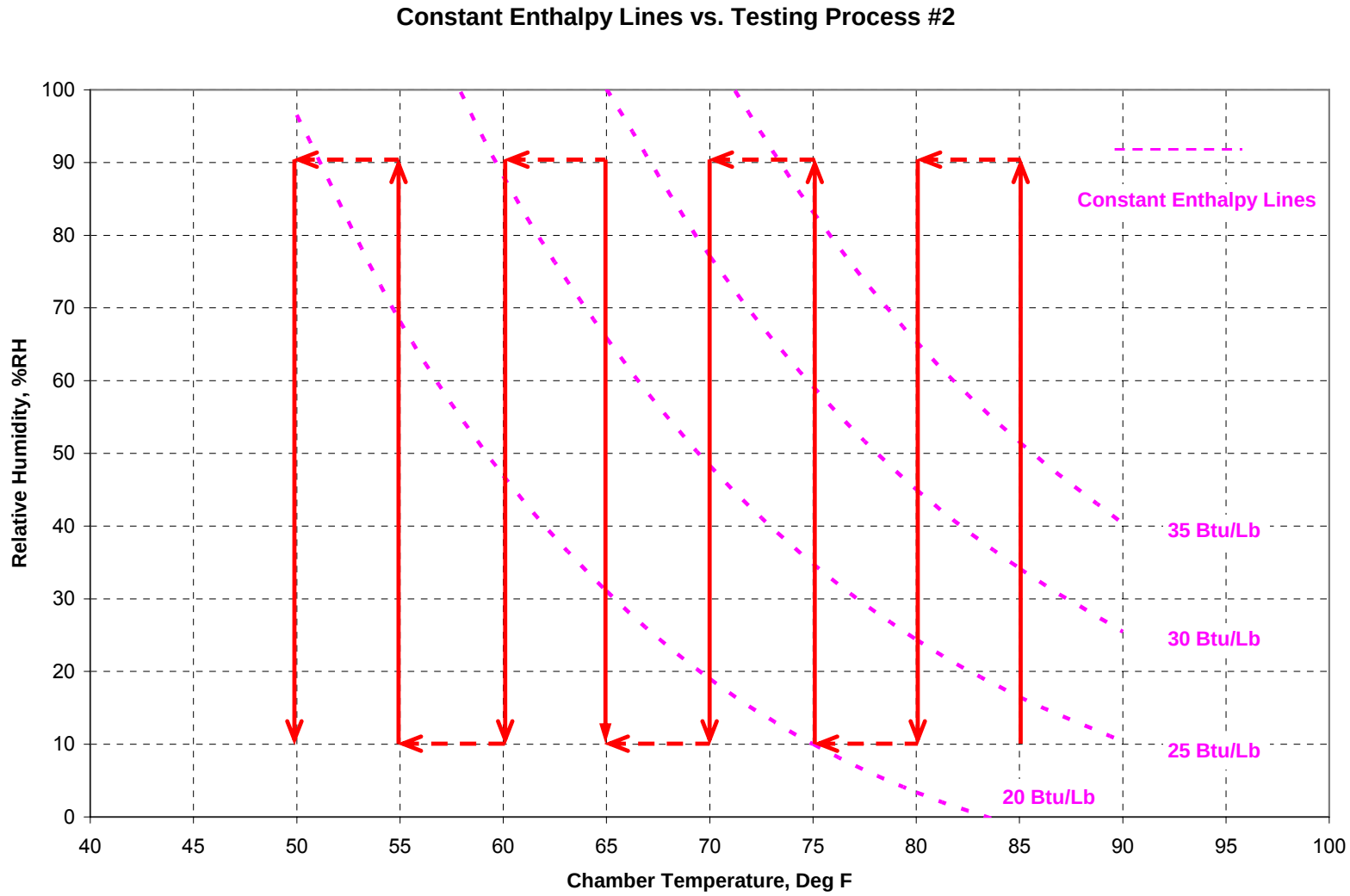
Test Procedure

- **Economizer Enthalpy Sensors – Step Increase In Temperature**



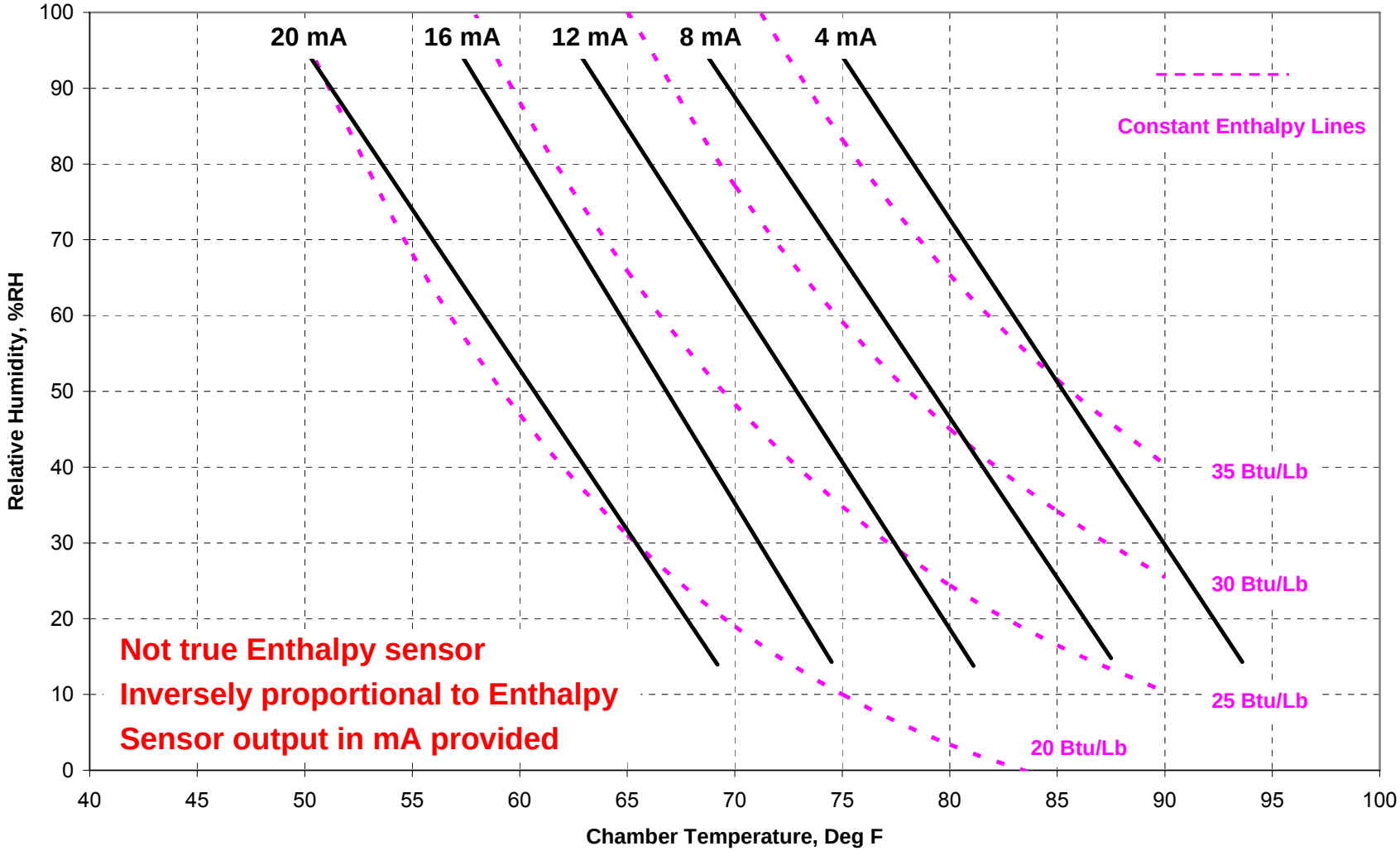
Test Procedure

- **Economizer Enthalpy Sensors – Step Decrease In Temperature**



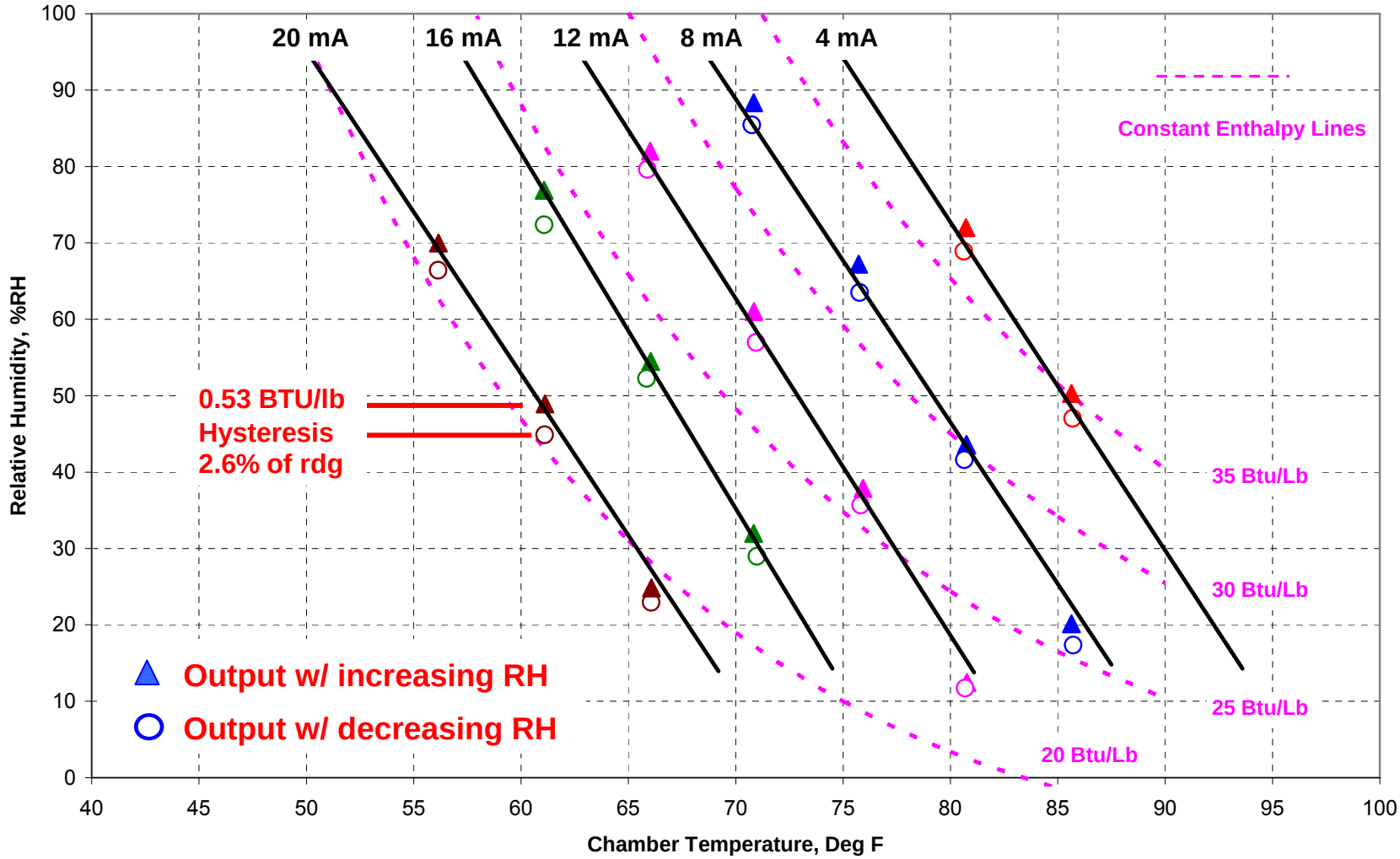
Pretest Data – Enthalpy Sensor #1

- **Manufacturer's Published Performance Data**



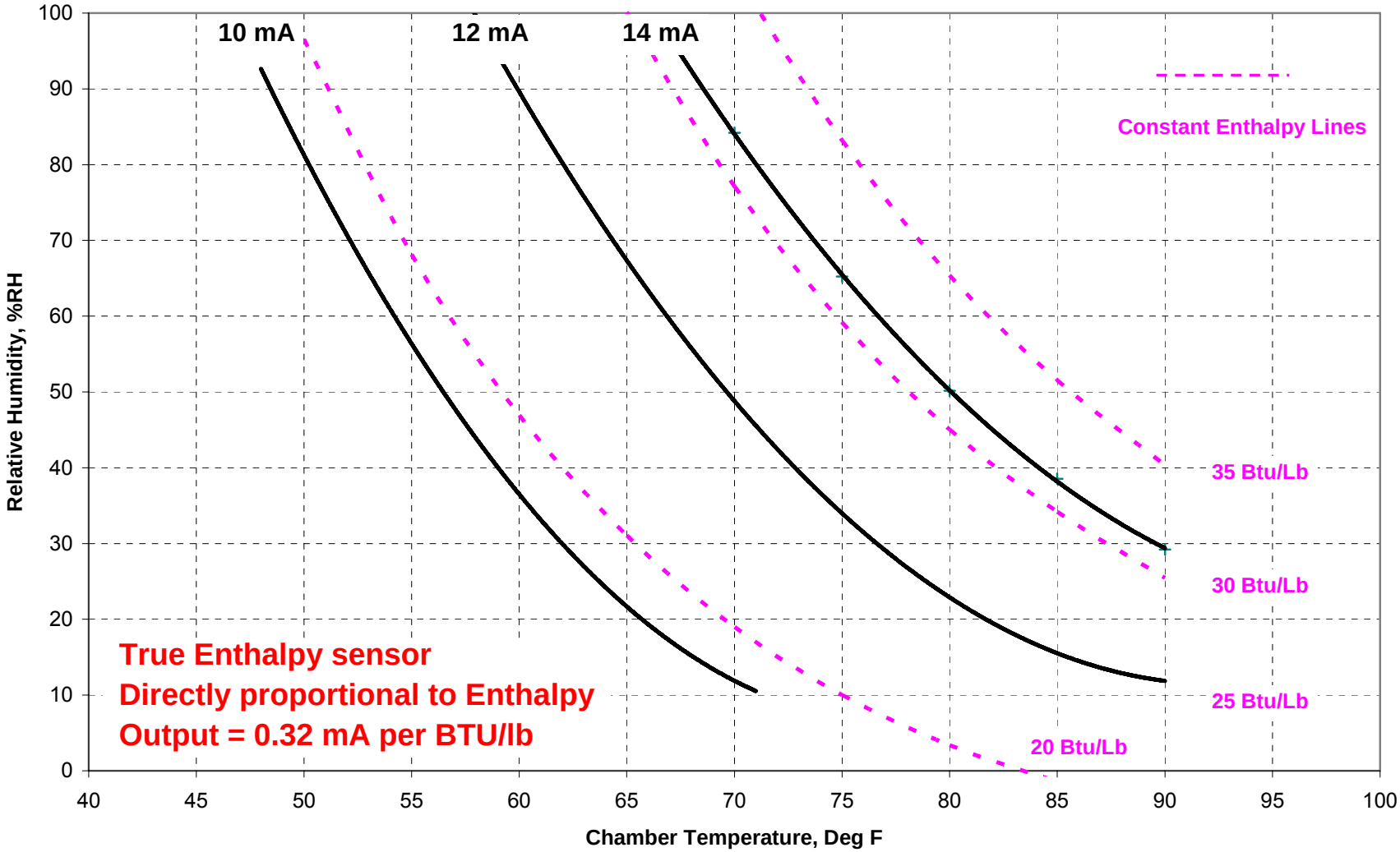
Pretest Data – Enthalpy Sensor #1

- **Actual Test Data – Manufacturer reference to mA Output**



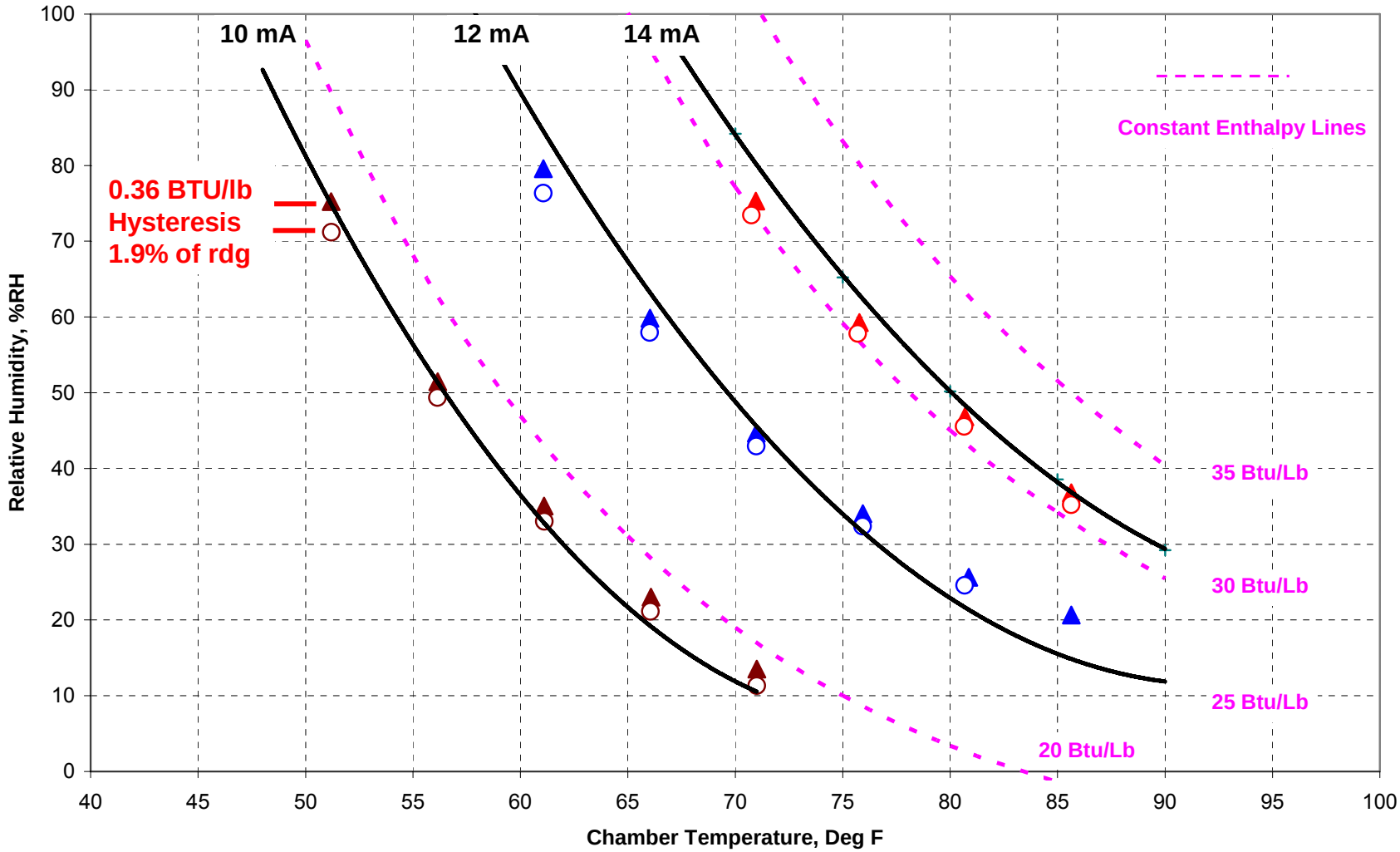
Pretest Data – Enthalpy Sensor #2

- **Manufacturer's Published Performance Data**



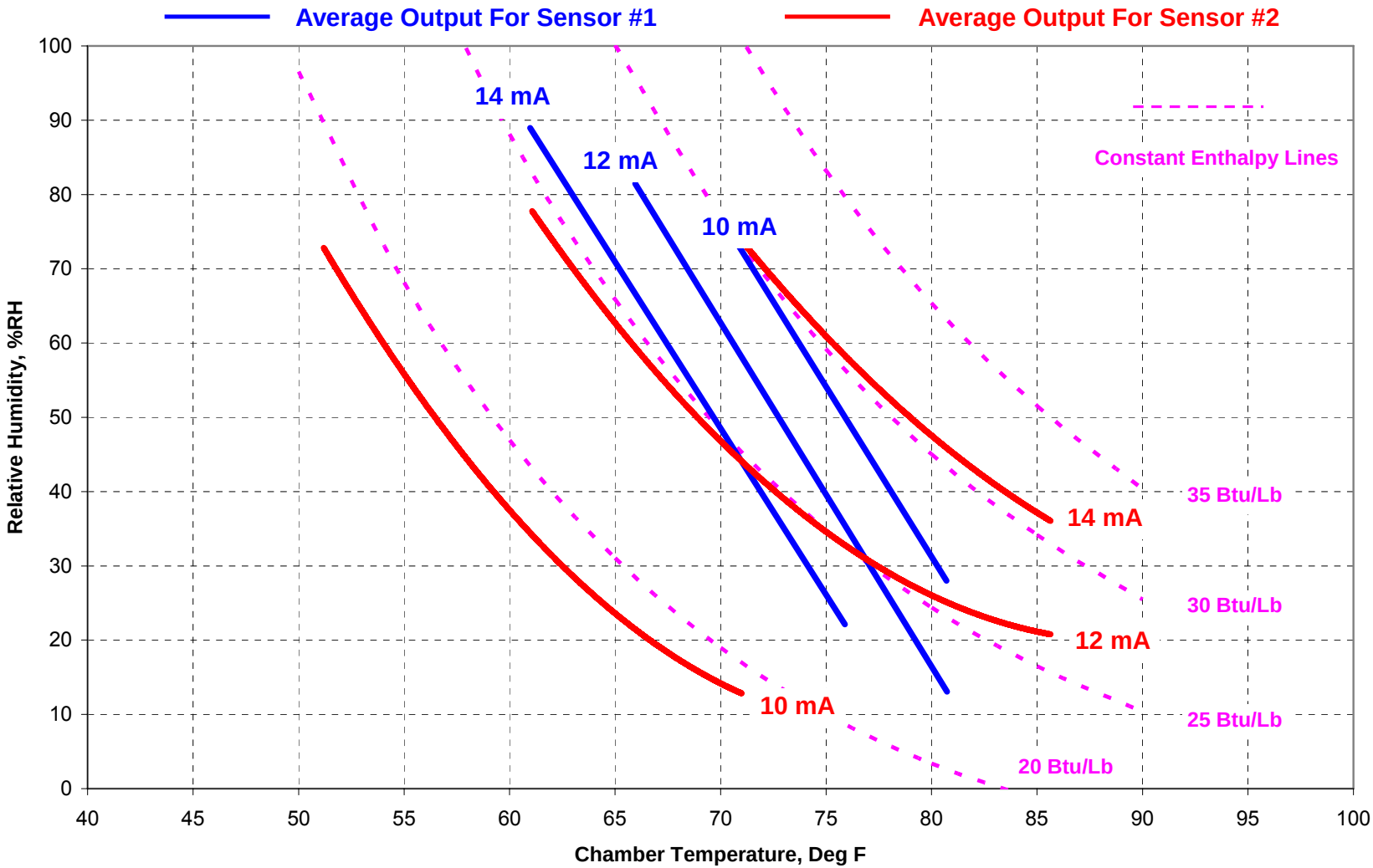
Pretest Data – Enthalpy Sensor #2

- **Actual Test Data**



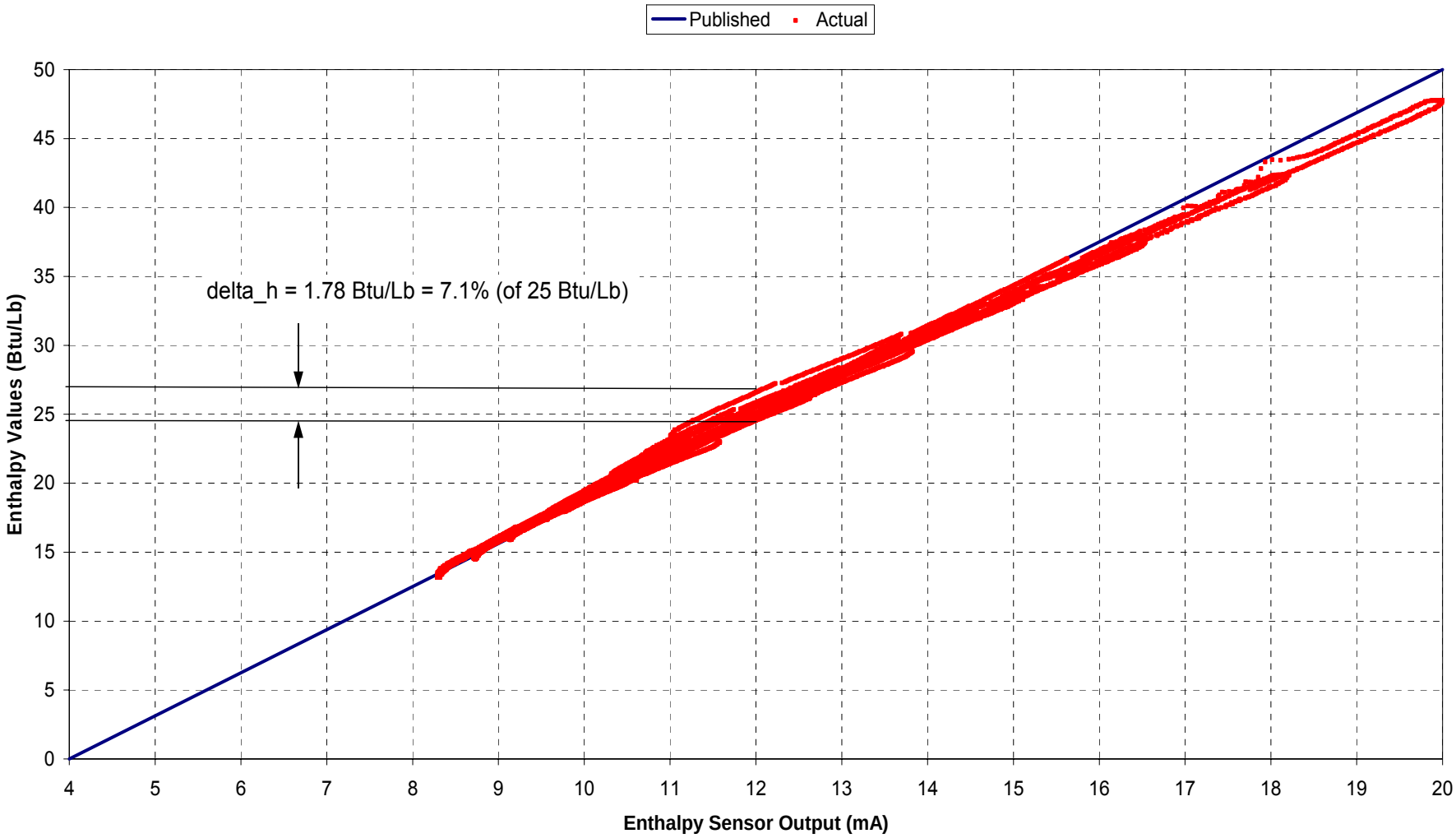
Pretest Data – Enthalpy Sensor #1 and #2

- **Actual Test Data**



Pretest Data – Enthalpy Sensor #2

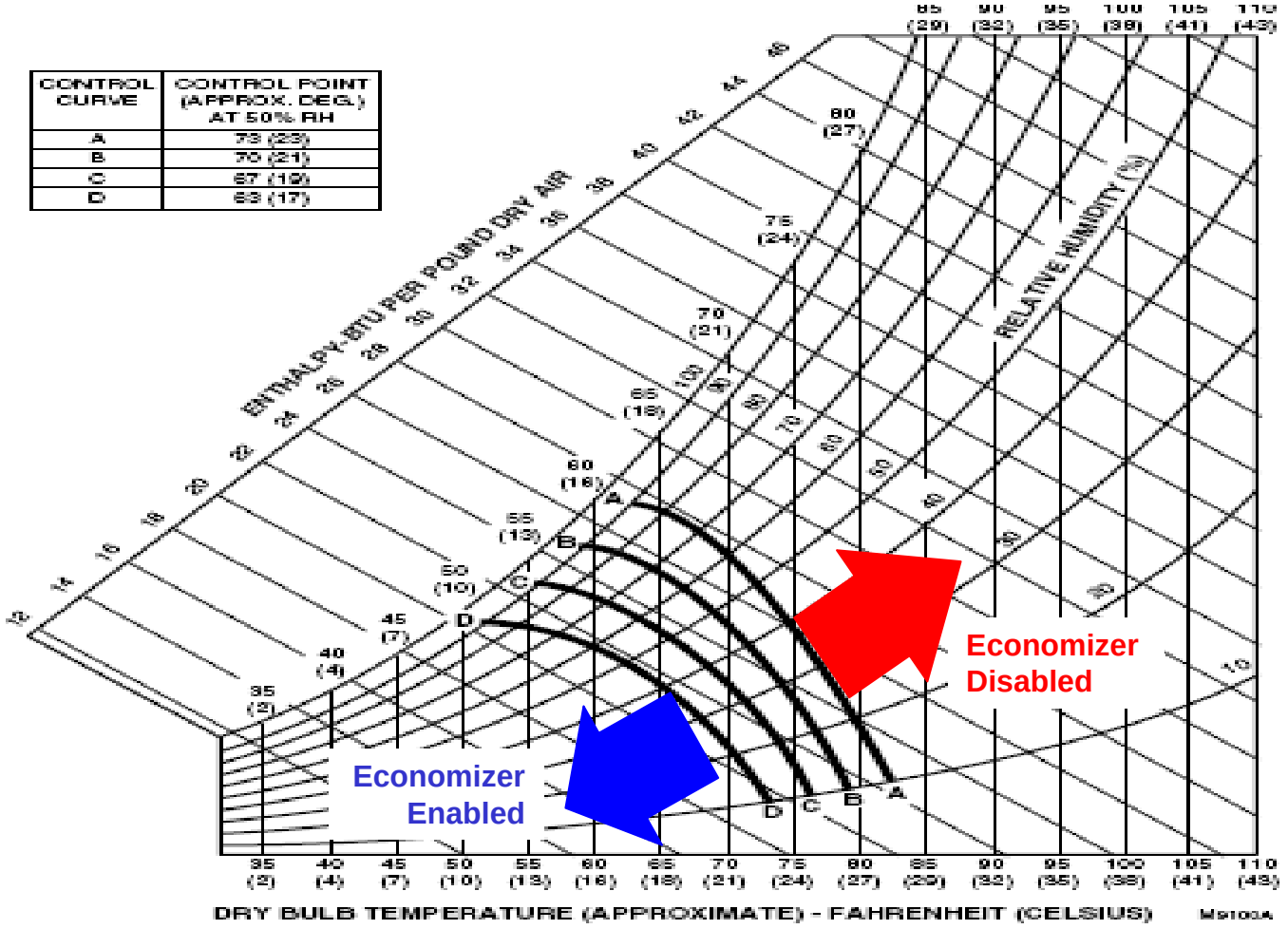
- **Manufacturer's Published Data vs Actual Test Data**



Pretest Data – Enthalpy Switch

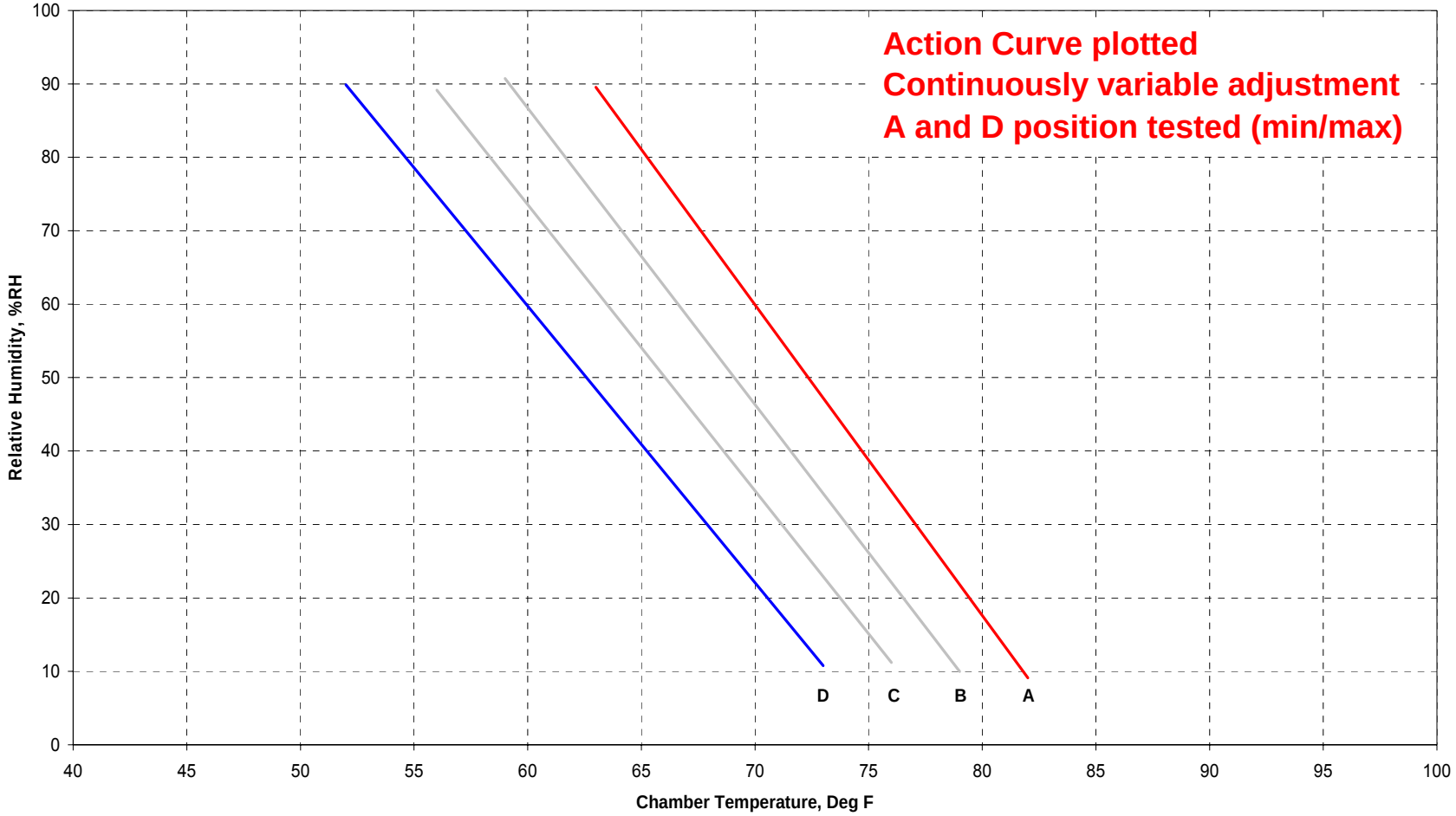
- **Manufacturer's Published Performance Data**
  - Typical enthalpy switch action curve

CONTROL CURVE	CONTROL POINT (APPROX. DEG.) AT 50% RH
A	73 (23)
B	70 (21)
C	67 (19)
D	63 (17)



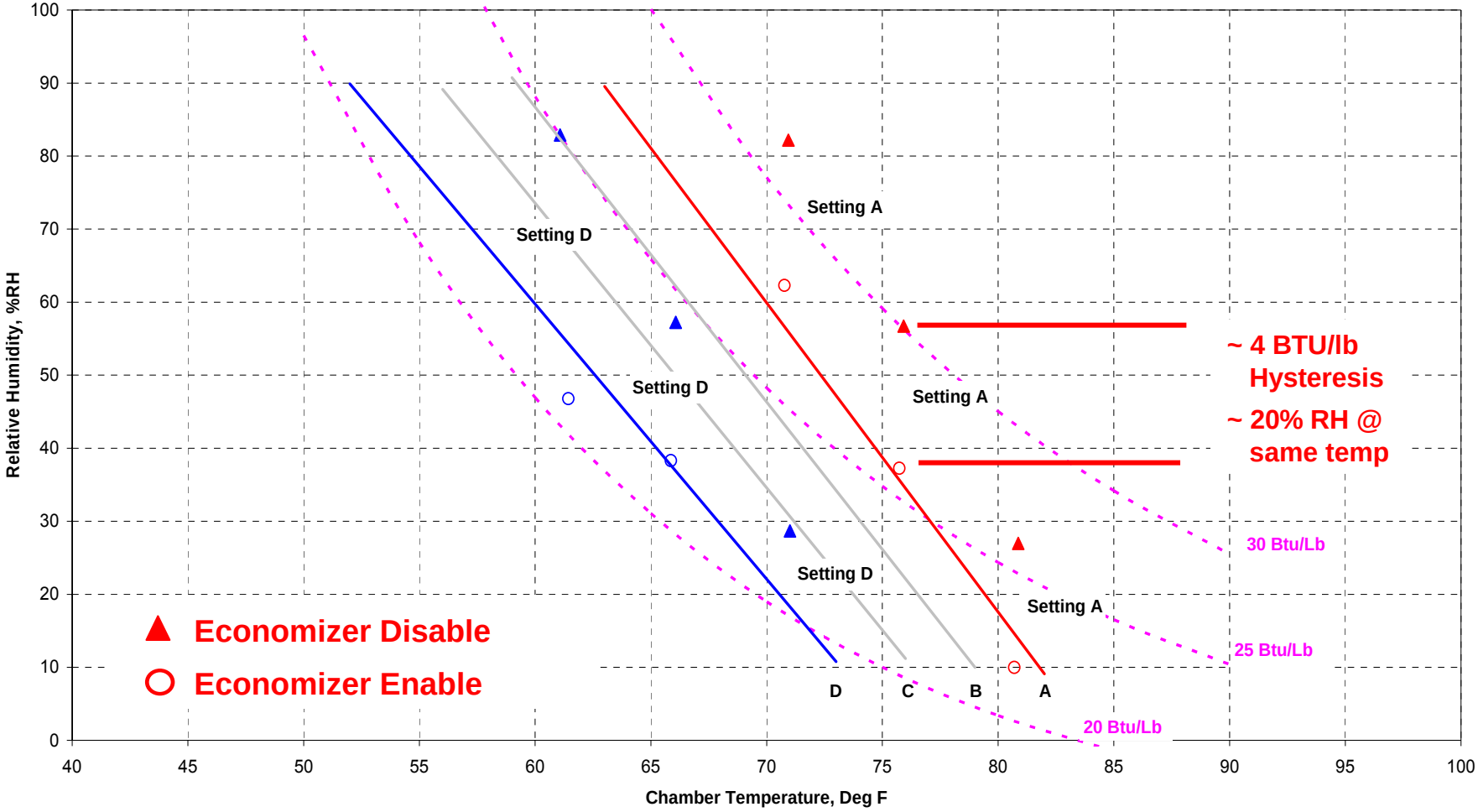
Pretest Data – Enthalpy Switch

- **Manufacturer's Published Performance Data**
  - Enthalpy switch action curve



Pretest Data – Enthalpy Switch

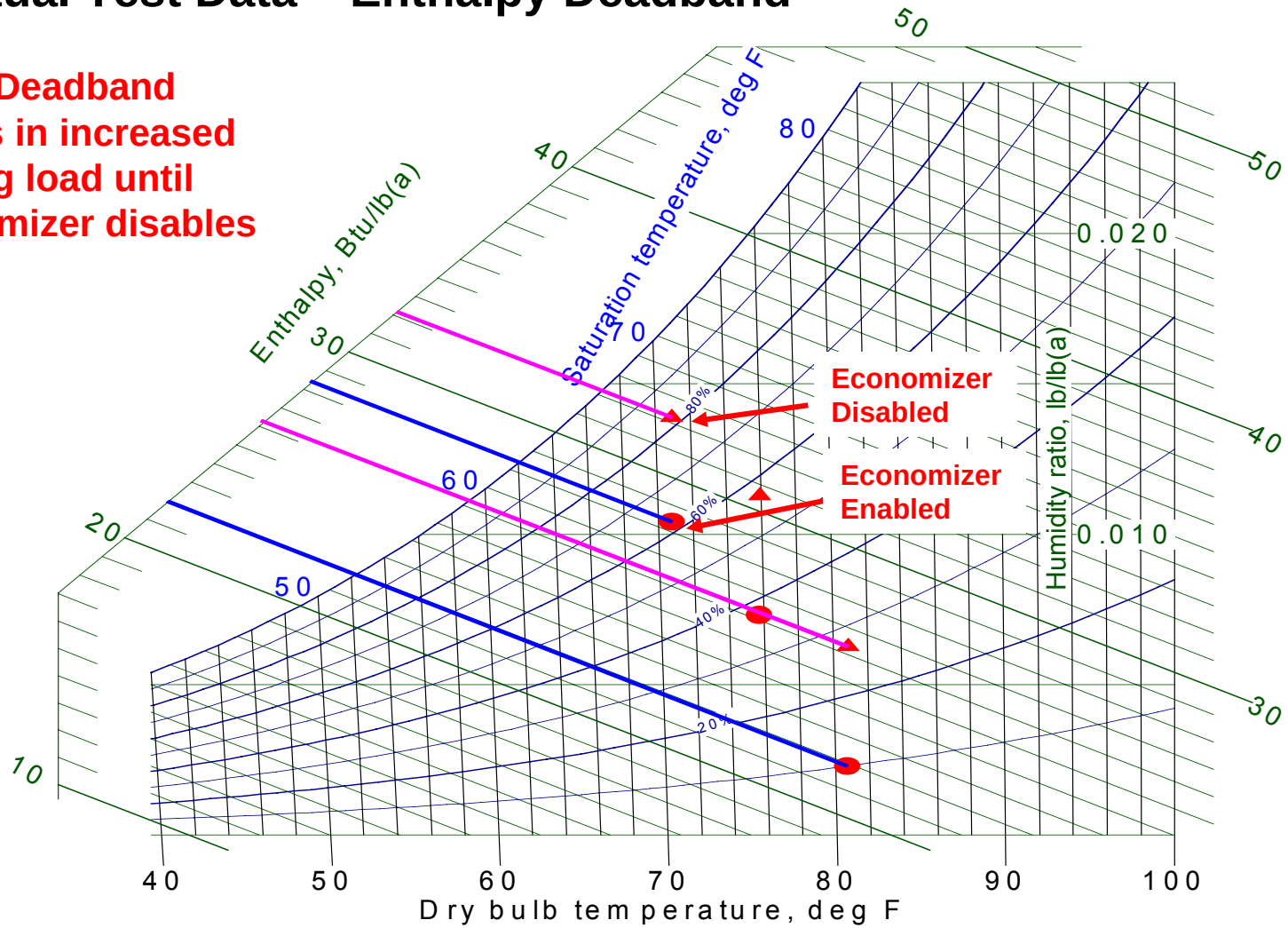
- **Actual Test Data**
  - Enthalpy switch action curve



Pretest Data – Enthalpy Switch

- **Actual Test Data – Enthalpy Deadband**

Large Deadband results in increased cooling load until Economizer disables



Pretest Data – Enthalpy Switch

- **Actual Test Data – Enthalpy Deadband**

Enthalpy (Btu/Lb)	61 °F	66 °F	71 °F	76 °F	81 °F	Average Deadband
Setting A - Enabled	X	X	27.9	25.9	21.8	4.2 BTU/Lb
Setting A - Disabled	X	X	31.6	30.1	26.0	
Setting D - Enabled	20.6	21.4	NA	X	X	3.7 BTU/LB
Setting D - Disabled	25.0	24.4	22.1	X	X	

Questions ???

Thank You !!!

- Contact Information

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- Resources
  - DDC Online: www.ddc-online.org
  - NBCIP Reports: www.buildingcontrols.org