

AHRI Update

Positive Displacement and Centrifugal Refrigerant Compressors

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Agenda

1. Introduction to AHRI
2. AHRI Standard 540-2019 (positive displacement)
3. AHRI Standard 1520P (centrifugal)
4. Uncertainty Limits in AHRI Compressor Standards

Introduction to AHRI

- **319 - Member Companies:** Over 95% of all HVACR products manufactured and installed in North America; more than 70% of global products
- **102 - AHRI standards and guidelines** in use across the globe
- **44 - AHRI Certification Programs:** Nearly 900 participants representing over 70% of all HVACR products manufactured globally

AHRI Standard 540-2019

Purpose and Development History

- Purpose
 - Provide the industry the ability to accurately compare compressors
 - Consistent method of presenting data
 - Ensure published data from a compressor manufacturer is within a defined uncertainty limit
- Development History
 - 2012 – AHRI 570/571 is updated to harmonize standard rating conditions with Europe and China
 - 2015 – AHRI 540 is updated to include operating map tolerances, superheat correction, and verification of published ratings for batches of equipment
 - 2017 – AHRI 545 is created to define requirements for modulating compressors
 - 2019 – AHRI 540 will be updated to include all types of positive displacement compressors

AHRI Standard 540-2019

Polynomial Equation – 3 requirements

1. Fixed Displacement

- One full-load polynomial equation

2. Discrete Modulating

- One polynomial equation for each discrete step

3. Continuous Modulating

- Three polynomial equations (maximum, minimum, mid point)

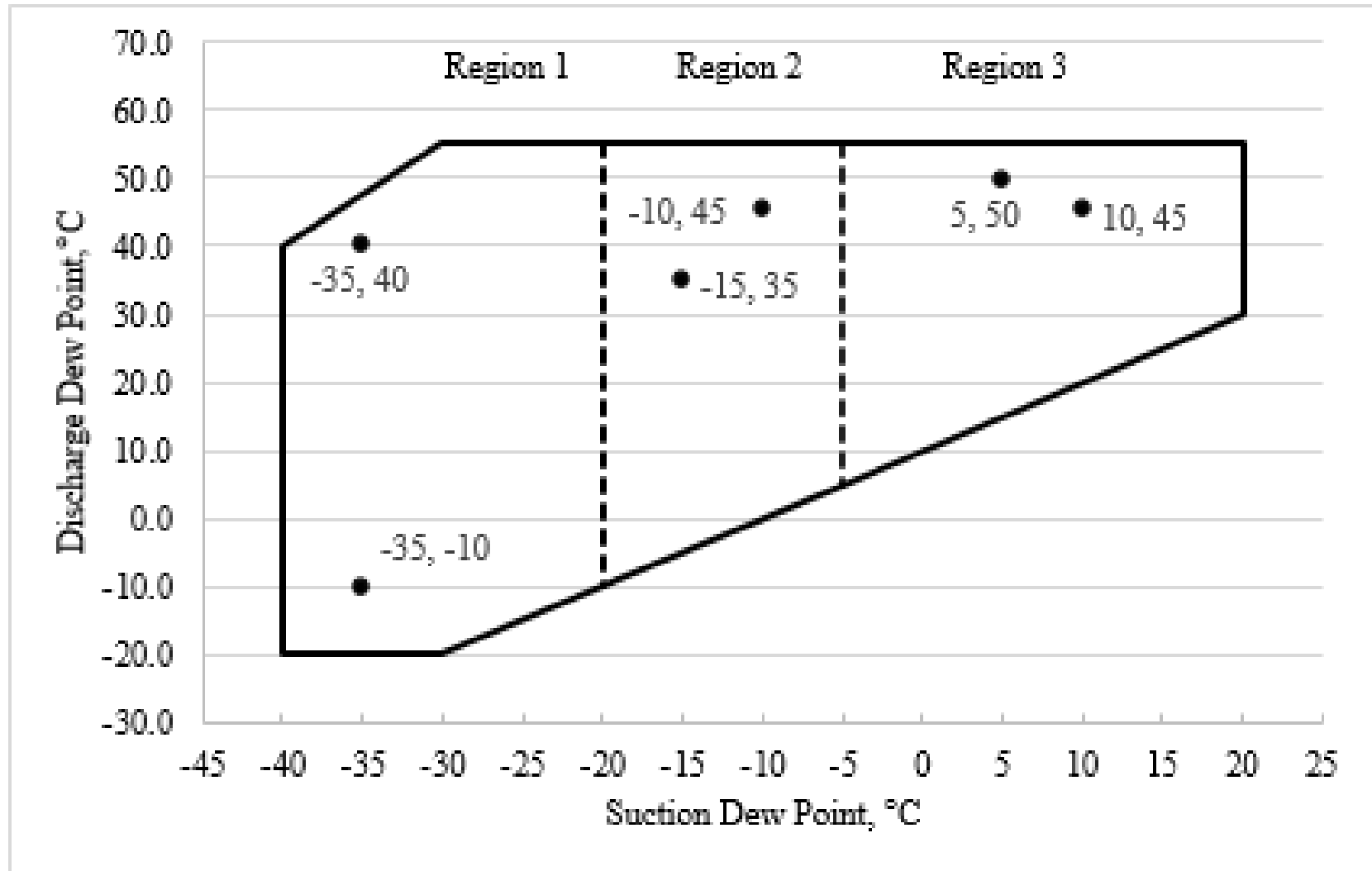
AHRI Standard 540-2019

4 Rating Methods

1. No Economizer
2. Economizer with Manufacturer Specified Heat Exchanger
3. Economizer with Non-Specified Heat Exchanger
4. Economizer with Flash Tank

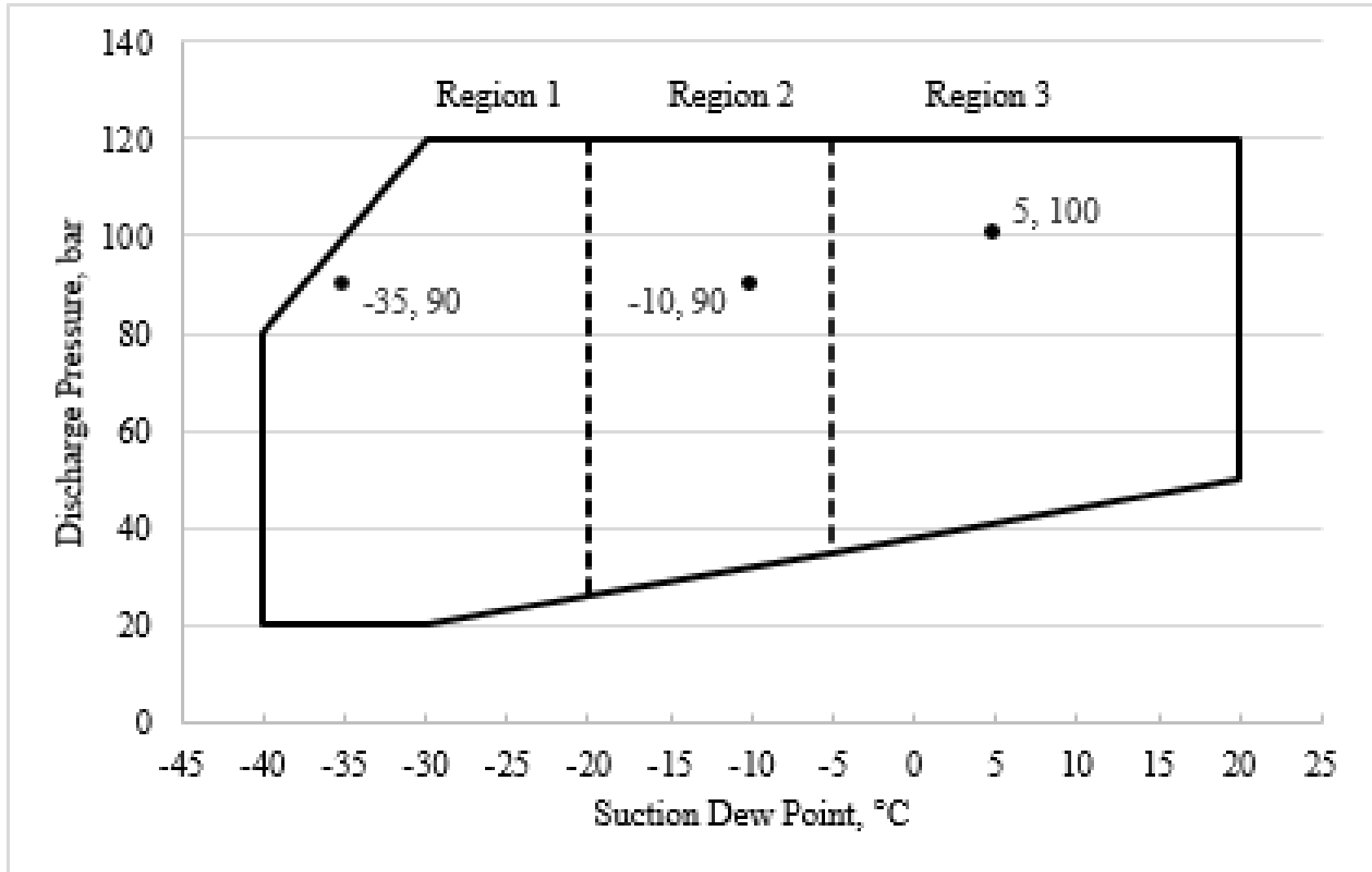
AHRI Standard 540-2019

Application Envelope – 3 Regions (subcritical)



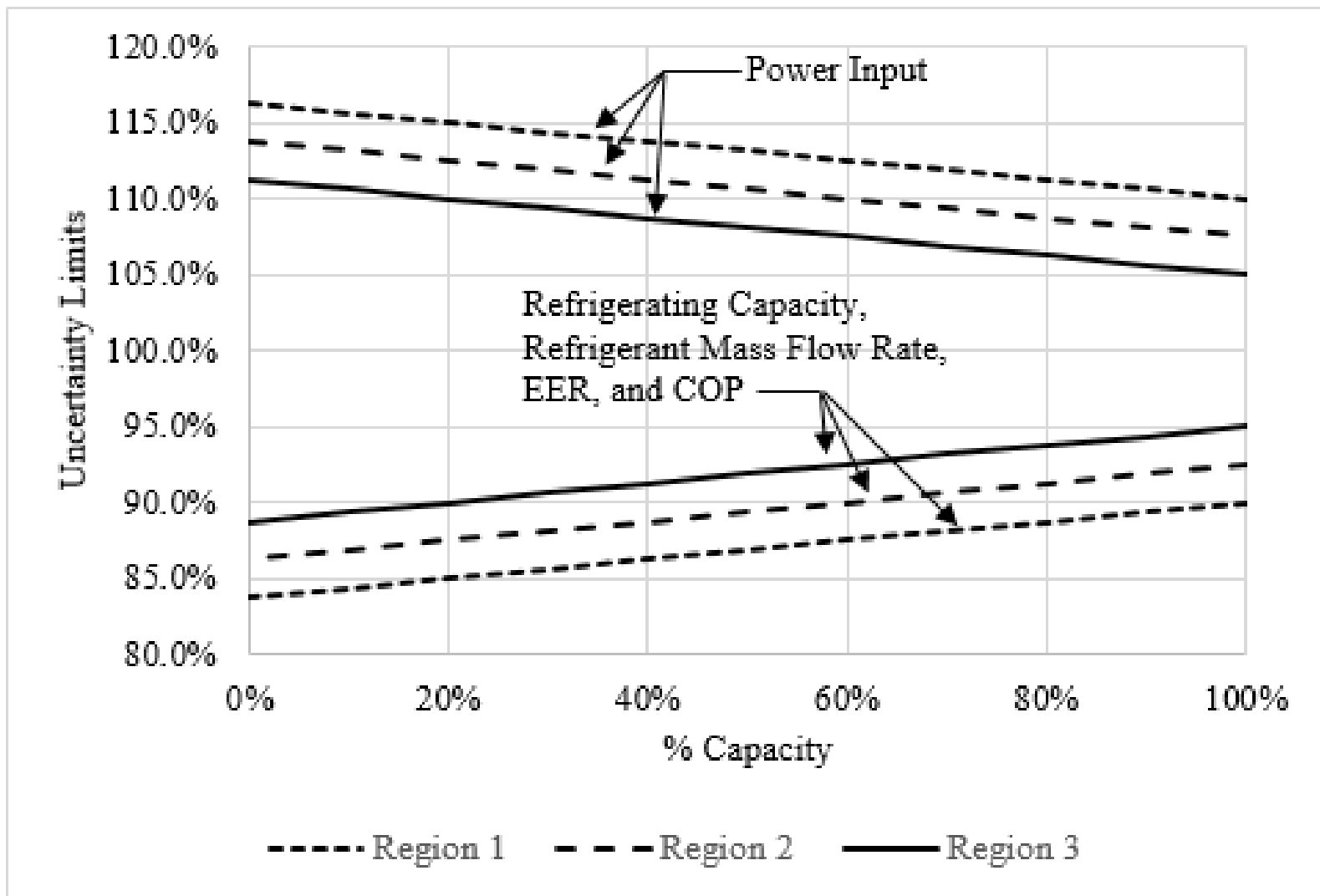
AHRI Standard 540-2019

Application Envelope – 3 Regions (supercritical)



AHRI Standard 540-2019

Rating Uncertainty Limits



AHRI Standard 540-2019

Reference Rating Conditions
(Harmonized with EN12900)

1. Air Conditioning and Heat Pump Conditions (Subcritical)
 - Heating
 - Cooling
2. Refrigeration Conditions (Subcritical and Transcritical)
 - High
 - Medium
 - Low

AHRI Standard 540-2019

Published Ratings

1. General
2. Operating Range
3. Performance Data (polynomial equation)
4. Additional Data for Modulating Compressors
5. Additional Data for Rating Methods 2, 3, and 4 or Interstage Heat Rejection

AHRI Standard 540-2019

Zeotropic Refrigerants

- Industry is having an increased focus on refrigerants with glide
 - Due to search for Low GWP solutions
- Impact of the glide is in the heat exchangers
 - Actual system runs at higher suction pressure and high discharge pressure in comparison to the dew point
 - Actual system capacity would be higher
 - Efficiency less impacted (about same)
- Why are compressors ratings based on Dew Point?
 - No glide inside of a compressor
 - Low pressure compressed to higher pressure
 - Mass flow measured
 - Power measured
 - Capacity is calculated!

AHRI Standard 540-2019

Zeotropic Refrigerants

- Predicting of glide calculation
 - Mid-point can be used as rough estimate
 - AHRI 540 Appendix C (informative)
 - Condensing pressure: Average of bubble point and dew point
 - Suction pressure: Average of TXV temperature and dew point
 - Subcooling will move this mid point
 - Actual saturated point could/should be obtained from heat exchanger manufacturer
- Compressors rated in accordance with a standard are still valid for zeotropic refrigerants due to rating of entire operating map
- Capacity should be calculated by system manufacturer based on heat exchange knowledge

AHRI Standard 540-2019

Superheat Correction

- Performance ratings established for specific superheat and/or return gas temperature
 - Appendix D of AHRI 540 (informative)
 - Superheat correction formulas
 - Based on suction densities
 - Correction factors should be provided by compressor manufacture for precise

$$\dot{m}_{\text{corrected}} = \{ 1 + F_v [(v_{\text{rated}} / v_{\text{corrected}}) - 1] \} \cdot \dot{m}_{\text{rated}} \quad \text{D1}$$

Where:

F_v = Volumetric efficiency correction factor – the correction factor will vary based on volumetric efficiency of the compression technology used, a value of one (1) can be used for an approximation. Contact the manufacturer for a more precise value.

$\dot{m}_{\text{corrected}}$ = Refrigerant Mass Flow Rate at suction condition, lbm/h, kg/s

\dot{m}_{rated} = Refrigerant Mass Flow Rate at rated superheat, lbm/h, kg/s

$v_{\text{corrected}}$ = Specific volume at suction condition, ft³/lbm, m³/kg

v_{rated} = Specific volume at rated condition, ft³/lbm, m³/kg

AHRI Standard 540-2019

Published Ratings for a Population of Compressors

Table E1. Rating Uncertainty Limits Using a Sample Size of 3

Published Rating		Region 1	Region 2	Region 3
Refrigerant Mass Flow, lb/min Refrigerating Capacity, Btu/h EER, Btu/W·h COP, W/W	Full Load	Tested Rating \geq 94.5% of Published Rating	Tested Rating \geq 95.5% of Published Rating	Tested Rating \geq 97.0% of Published Rating
	Part Load	Tested Rating \geq (104.5% - UL_{R1}) of Published Rating	Tested Rating \geq (103% - UL_{R2}) of Published Rating	Tested Rating \geq (102% - UL_{R3}) of Published Rating
Power Input, kW	Full Load	Tested Rating \leq 105.5% of Published Rating	Tested Rating \leq 104.5% of Published Rating	Tested Rating \leq 103.0% of Published Rating
	Part Load	Tested Rating \leq (100% + UL_{R1}) of Published Rating	Tested Rating \leq (100% + UL_{R2}) of Published Rating	Tested Rating \leq (100% + UL_{R3}) of Published Rating

AHRI Standard 1520P

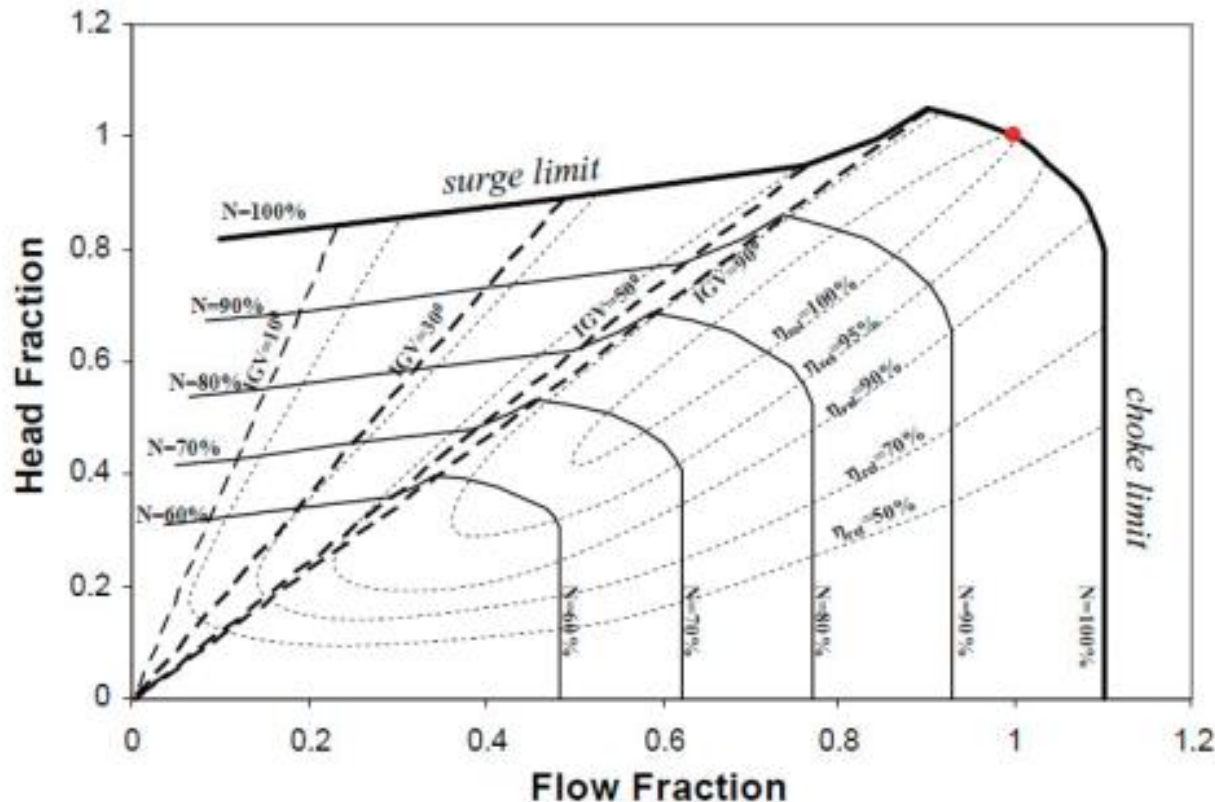
Purpose

- Standardize centrifugal compressor performance ratings
- Allow comparison of centrifugal and positive displacement compressor ratings

AHRI Standard 1520P

Reference Documents

- ASME, *Performance Test Code on Compressors and Exhausters*, PTC 10-1997.
- Brasz, J.J., *A Proposed Centrifugal Refrigeration Compressor Rating Method*, International Compressor Engineering Conference, 2010.



AHRI Standard 1520P

Performance Ratings

- Flow Factor:

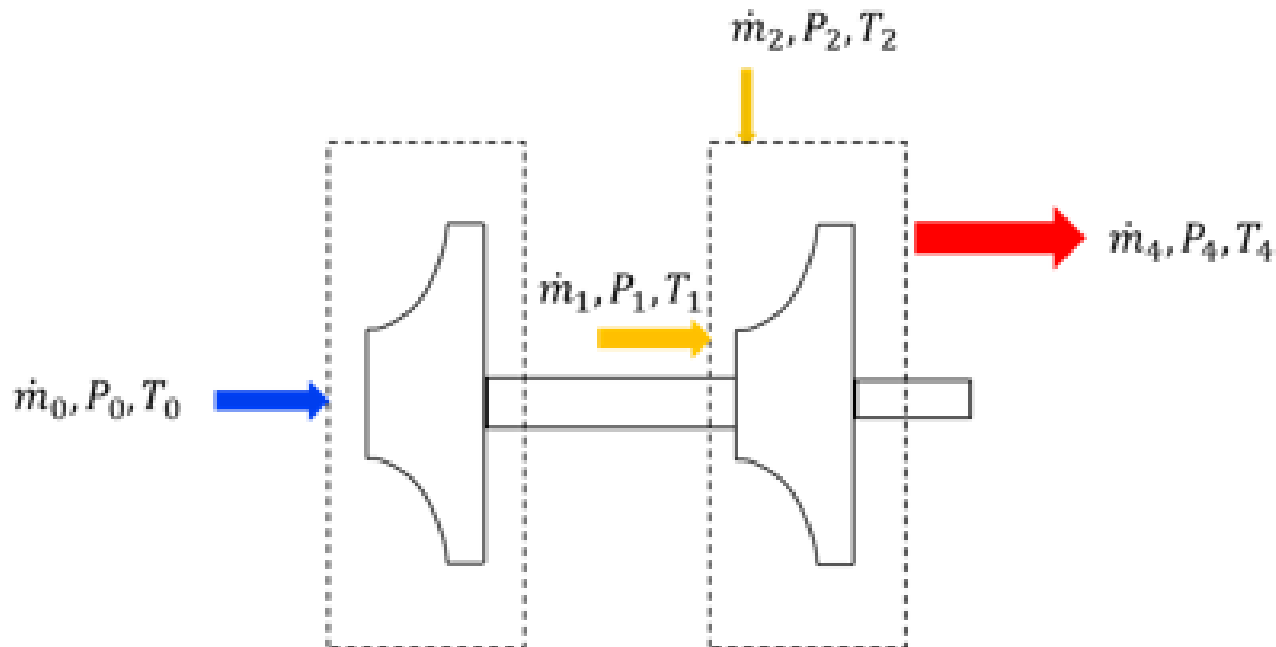
$$FF = \frac{\dot{m}_0}{\rho_0 a_0}$$

- Head Factor:

$$HF = \frac{\Delta h_s}{a_0^2}$$

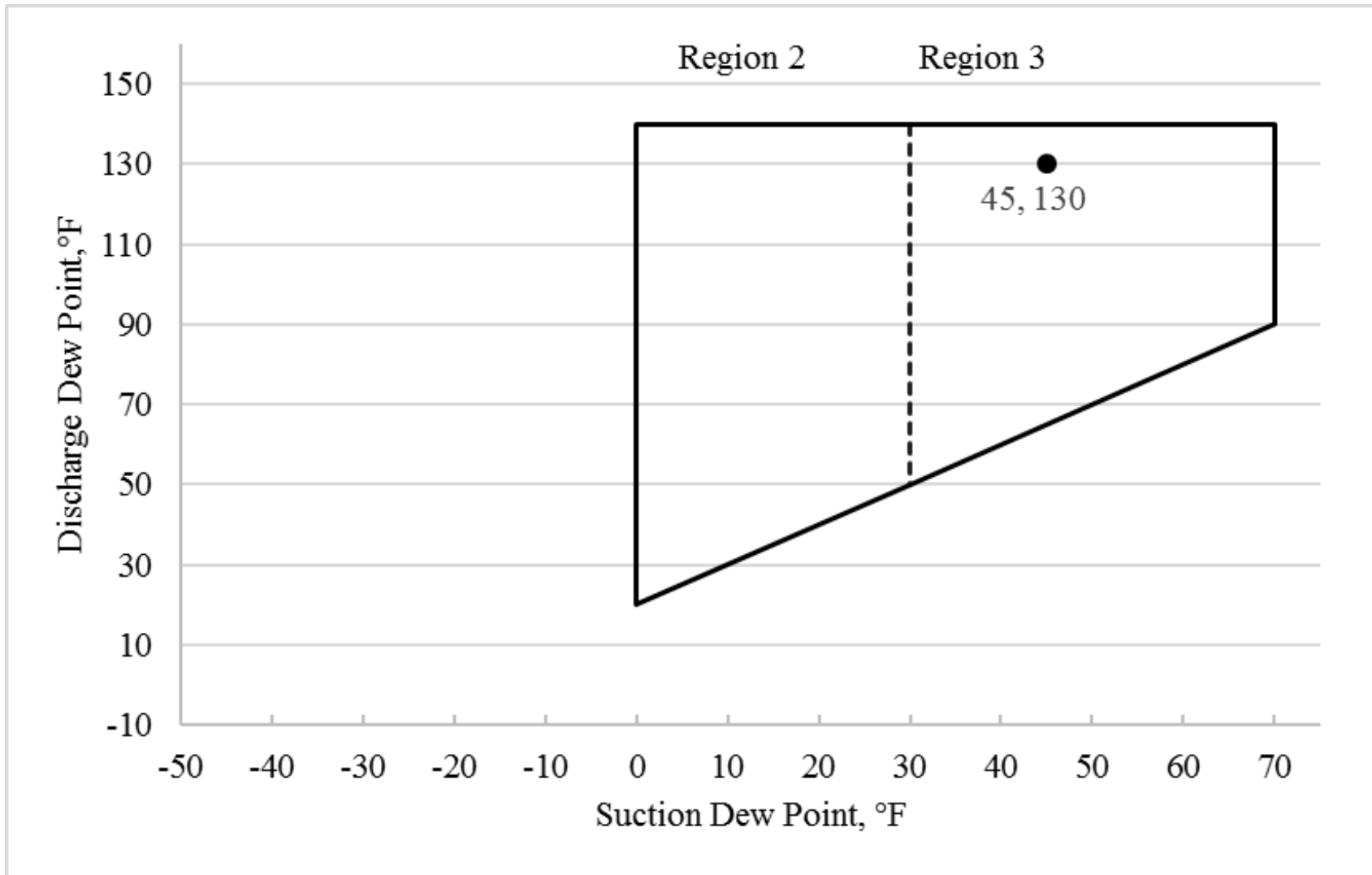
- Isentropic Efficiency:

$$\eta_{is} = \frac{\Delta h_s}{\Delta h_a}$$



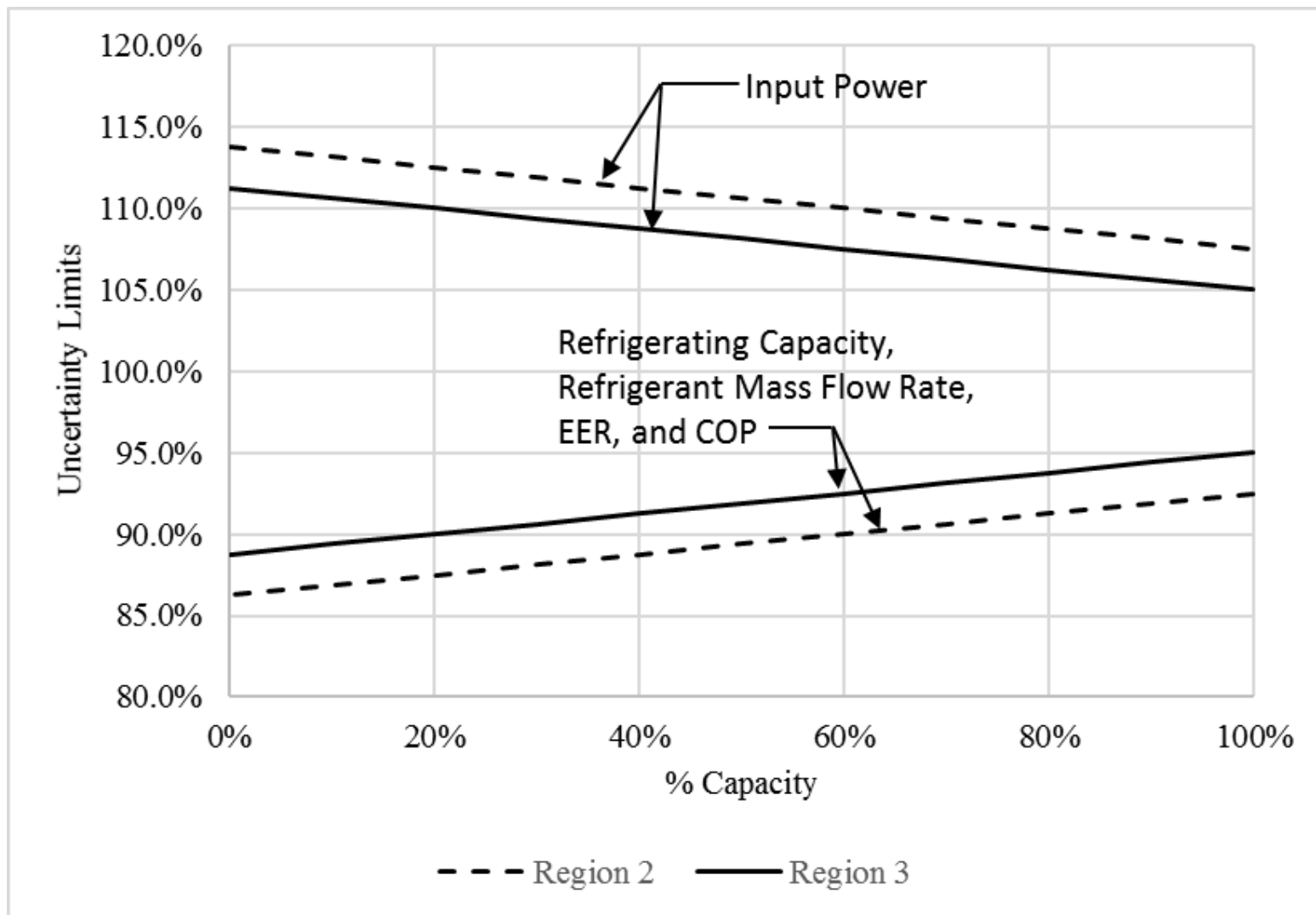
AHRI Standard 1520P

Application Envelope – 2 Regions (subcritical)



AHRI Standard 1520P

Rating Uncertainty Limits



AHRI Standard 1520P

Method of Test

ASHRAE 225P

1. Based on ASHRAE 23.1, *Methods of Testing for Rating the Performance of Positive Displacement Refrigerant Compressors and Condensing Units that Operate at Subcritical Temperatures of the Refrigerant*
2. Includes calculation for flow factor, head factor, and thermodynamic efficiency

Uncertainty Limits in AHRI Compressor Standards

Basis

TOLERANCES AND UNCERTAINTIES IN PERFORMANCE DATA OF REFRIGERANT COMPRESSORS

JANUARY 2017

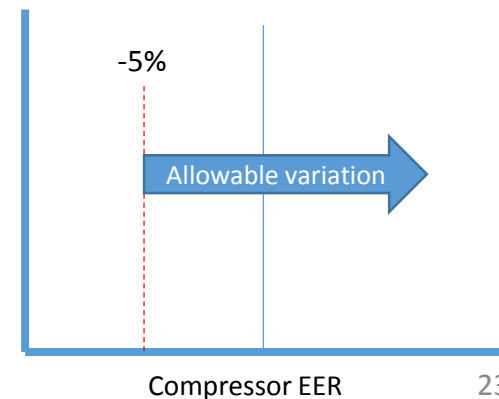
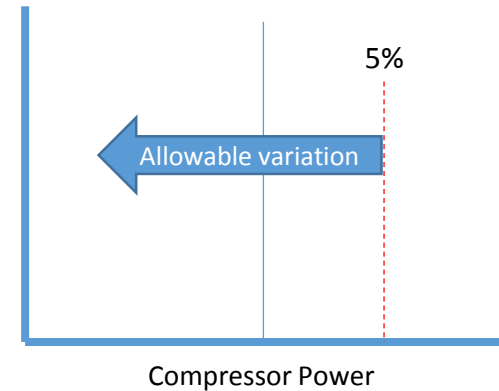
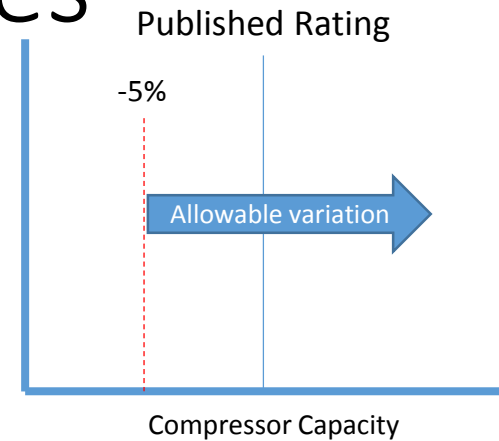
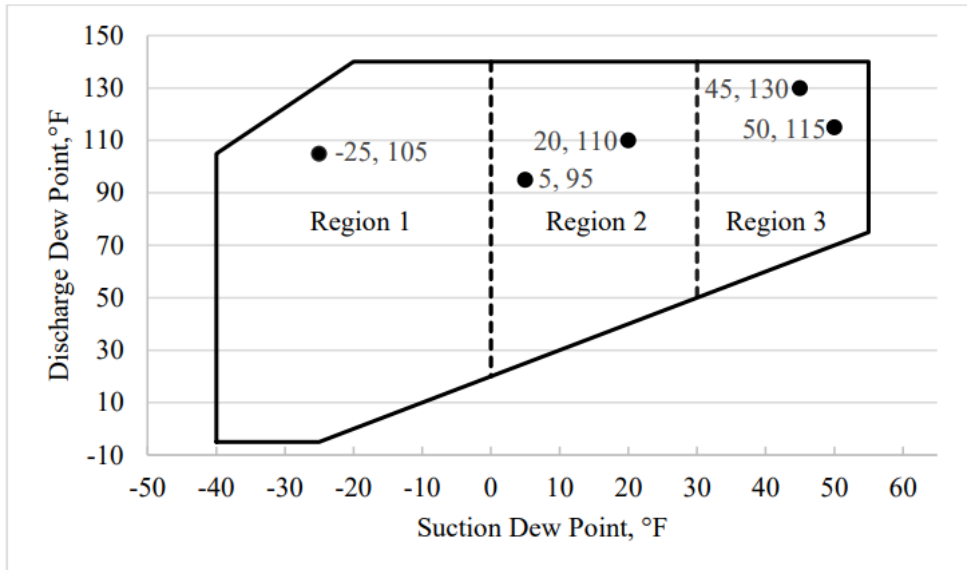


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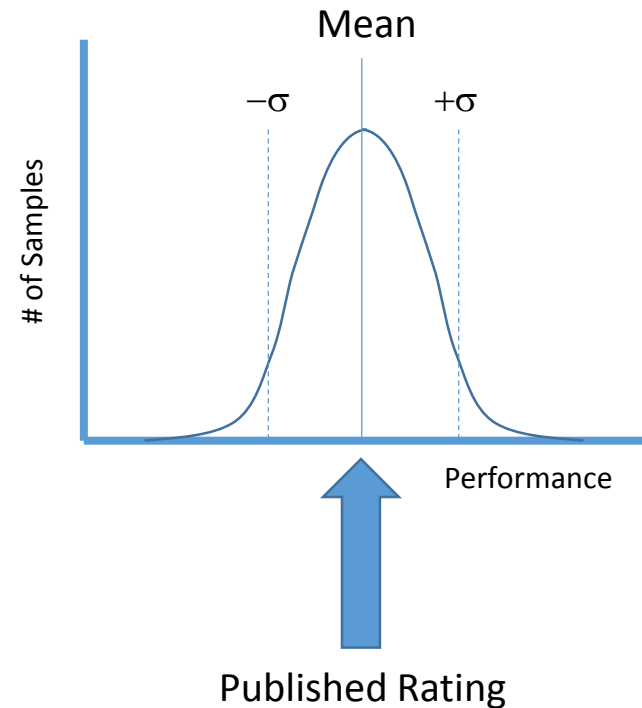
Compressor Rating Tolerances

- Published ratings refer to mean performance
 - AHRI 540
 - EN 12900
- Standards specify allowable tolerances on the rating data
 - 5% High Temp
 - 7.5% Medium Temp
 - 10% Low Temp



Compressor Performance Uncertainty

- Inherent in compressor performance is variation or uncertainty.
- Distribution of performance data is expressed by a mean and standard deviation (σ) and assumed to be a normal distribution.
- Compressor ratings published per the AHRI standards (540, 545, 570) require that the rating data represents the mean performance level of that compressor.



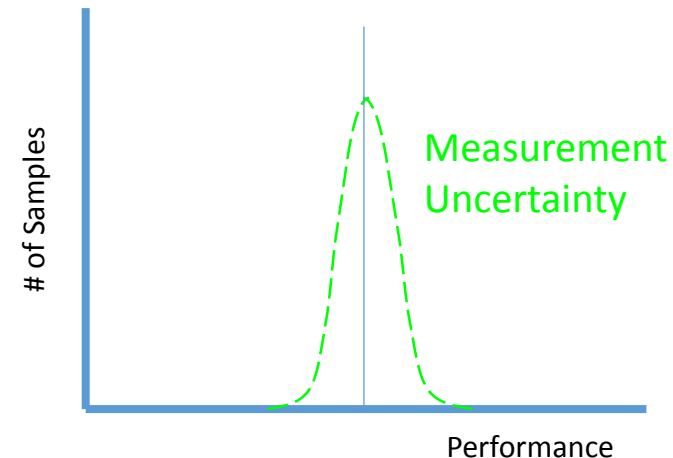
AHRI/ASERCOM White Paper

- Study co-sponsored by AHRI and ASERCOM looked into the sources of uncertainty in compressor performance.
- Identified 5 Sources of uncertainty:
 - Measurement System Uncertainty
 - Lab-to-Lab Variation
 - Manufacturing Variation
 - Performance Prediction Error
 - Tested vs. Rated Condition
- Total compressor uncertainty is determined based on the accumulating effects of sources of uncertainty.



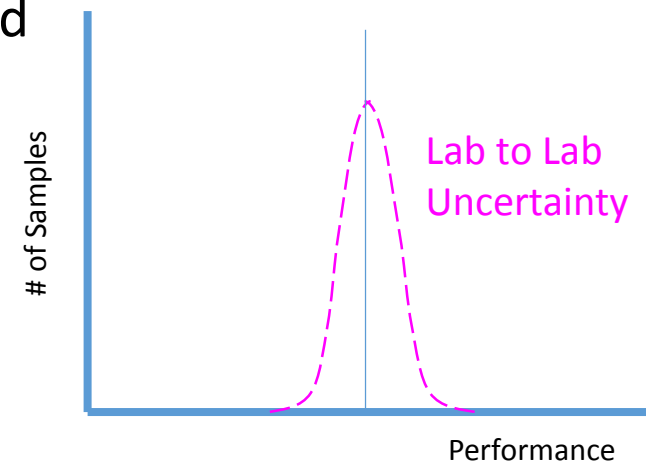
Measurement System Uncertainty

- Type of Measurement Uncertainty
 - Type A – Statistical variation. Repeatability of a single measurement.
 - Type B – Bias built into the measurement system (addressed in the next slide).
- Uncertainty allowed by ASHRAE 23 and EN 13771
 - Temperature ± 0.3 K resp ± 0.5 °F
 - Temperature differences $\pm 1\%$ of the difference
 - Pressure $\pm 1\%$ of value
 - Electrical power $\pm 1\%$ of value
- Standard allowable uncertainties equate to
 - $\pm 1.5\%$ on capacity at high temperatures
 - $\pm 2.1\%$ on capacity at low temperatures
 - $\pm 1.3\%$ on power
 - $\pm 2\%$ on COP at high temperatures
 - $\pm 3\%$ on COP at low temperatures



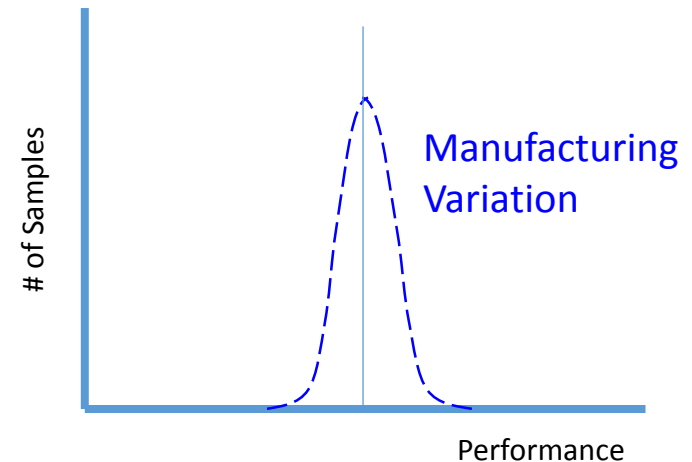
Lab-to-Lab Uncertainty

- Lab-to-Lab refers to the reproducibility of a measurement from one facility to another.
- The uncertainties (Type B) among laboratories are based on:
 - Calibration of measurement devices
 - Measurement methods, such as volume flow measurement or mass flow measurement on suction or discharge site
 - Quality of electrical power grid
 - Refrigerant properties or refrigerant properties database
- ASERCOM Study of seven European labs showed
 - R404A operation at low temperatures
 - Cooling capacity +/- 2.1%
 - Power consumption +/- 1.2%
 - COP/EER +/- 2.3%
 - R404A operation at medium temperatures
 - Cooling capacity +/- 1.5%
 - Power consumption +/- 1.5%
 - COP/EER +/- 1.8%



Manufacturing Variation

- Variation occurs in, but not limited to, these factors:
 - Dimensional variability in mechanical components
 - Internal gas leaks
 - Rotor & gate leakage in rotary compressors
 - Wrap leakage in scroll compressors
 - Rotor to rotor and rotor to bore leakage in screw compressors
 - Discharge and suction valve leakage
 - Varying effect of clearance volume in reciprocating compressors across the operating range
 - Bearing alignments
 - Electric motor efficiency
 - Mechanical losses in friction surfaces
- Typical product variability in cooling capacity is around $\pm 1.5\%$.

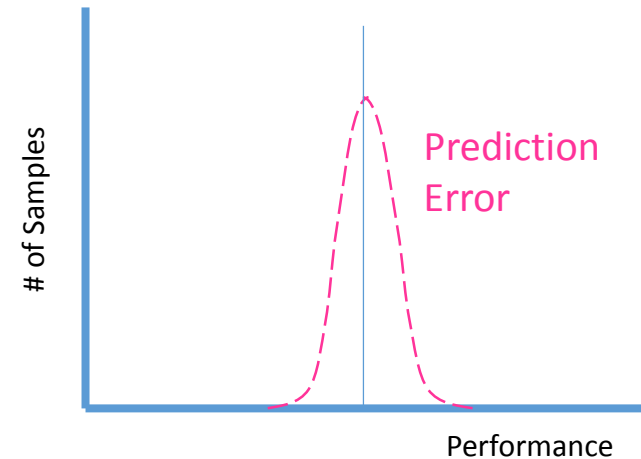
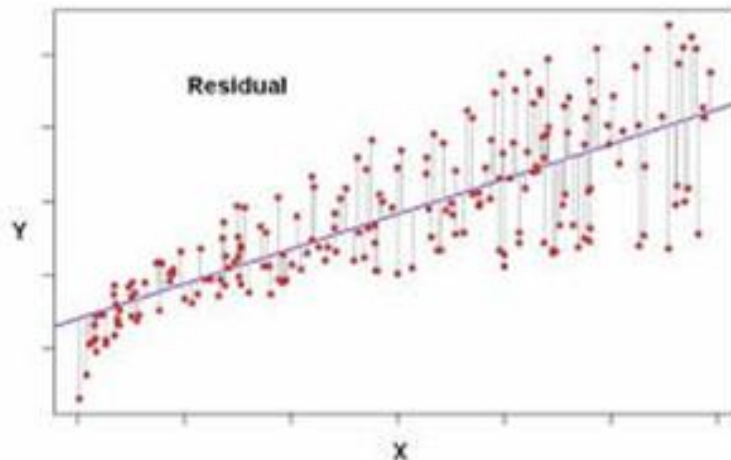


Performance Prediction Error

- AHRI performance standards require that compressor ratings use a 10-coefficient polynomial equation:

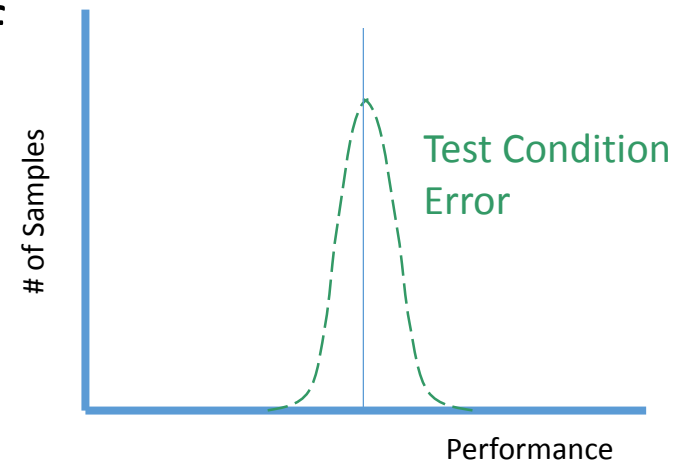
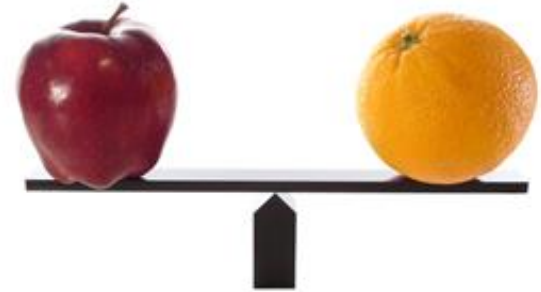
$$X = C1 + C2(T_s) + C3(T_d) + C4(T_s^2) + C5(T_s T_d) + C6(T_d^2) + C7(T_s^3) + C8(T_s^2 T_d) + C9(T_s T_d^2) + C10(T_d^3)$$

- C1 through C10 = Regression coefficients
 - T_d & T_s = Discharge & Suction dew point temperature, °F, °C
 - X = Performance metric (capacity, power, EER or mass flow rate)
- Aute and Martin evaluated the regression uncertainty for this equation and showed average uncertainty as high as 4% and 5% for mass flow rate and power, respectively.



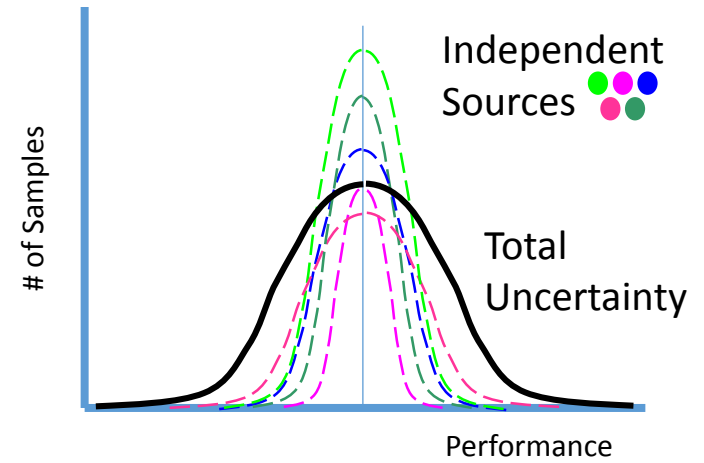
Tested vs. Rated Condition Error

- Compressor testing standards allow for deviations in the input from basic/specified test conditions.
- Difference between actual test conditions and specified test conditions can create errors in mass flow/capacity and power of order 1.5% and 2% respectively.
- The actual test condition may be further away from the specified test condition if the system is not stable or in transient condition while the test parameters are being recorded.



Total Uncertainty

- Need to combine these independent sources of uncertainty
- Total uncertainty is calculated by summing squared deviations from the mean.
- Combining the independent uncertainties provides a total uncertainty in the published rating
 - $\pm 5.0\%$ on Capacity
 - $\pm 4.9\%$ on Power



Source	High Temp Suction Conditions			
	Capacity		Power	
	Uncertainty	Variability	Uncertainty	Variability
Measurement	$\pm 1.5\%$	$(1.5\%)^2$	$\pm 1.3\%$	$(1.3\%)^2$
Lab-to-Lab	$\pm 1.5\%$	$(1.5\%)^2$	$\pm 1.5\%$	$(1.5\%)^2$
Manufacturing	$\pm 1.5\%$	$(1.5\%)^2$	*	*
Prediction	$\pm 4.0\%$	$(4.0\%)^2$	$\pm 4.0\%$	$(4.0\%)^2$
Test	$\pm 1.5\%$	$(1.5\%)^2$	$\pm 2.0\%$	$(2.0\%)^2$
Total Variability		0.0025		0.0024
Total Uncertainty	$\pm 5.0\%$	↪	$\pm 4.9\%$	↪

*Only capacity variation was studied. Power variation is also expected, but not shown here.

Questions?