Measuring and Rating the Performance of Domestic Refrigerating Appliances

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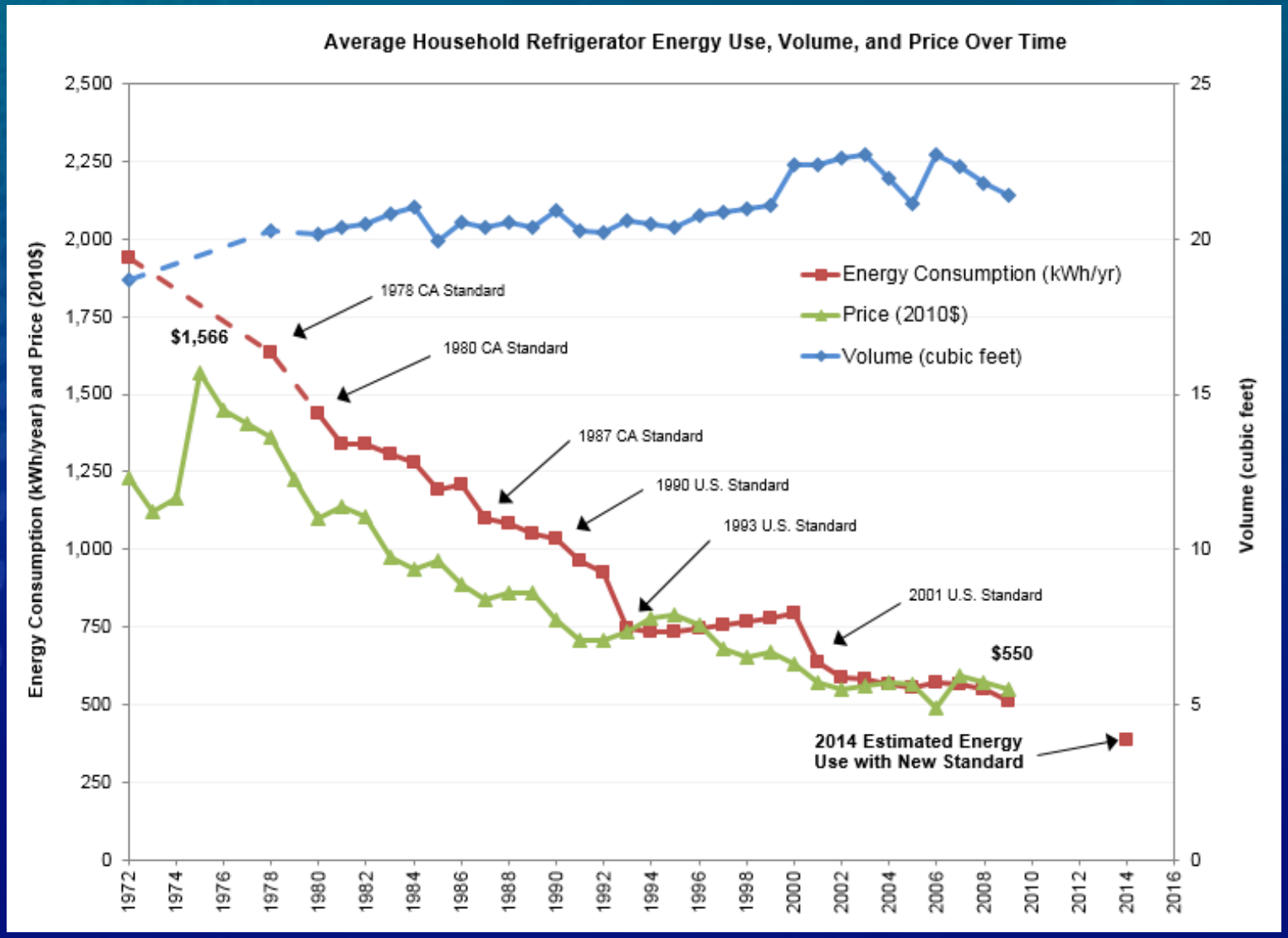
Outline

- History
- Refrigerator Operation and Energy Use
- U.S. Test Method Overview
- Equipment and Facilities
- Data Manipulation
- Circumvention
- Summary

History

- Energy Regulations for domestic refrigerators began in response to energy crisis of 1970s
  - State regulations began to emerge in the late 1970s
  - Federal regulations initiated in 1987
- Since initiating these programs the energy consumed has **decreased by 75%** while
  - Units have gotten 25% larger
  - Much more functional (special compartments, ice & water, etc.)
  - Better temperature and humidity control
- U.S. program is based on the test method maintained by the Association of Home Appliance Manufacturers (AHAM) – HRF-1
- Other methods exist including JIS C9801, AUS/NZ 4474.1, ISO 15502 → IEC 62552
  - International harmonization effort

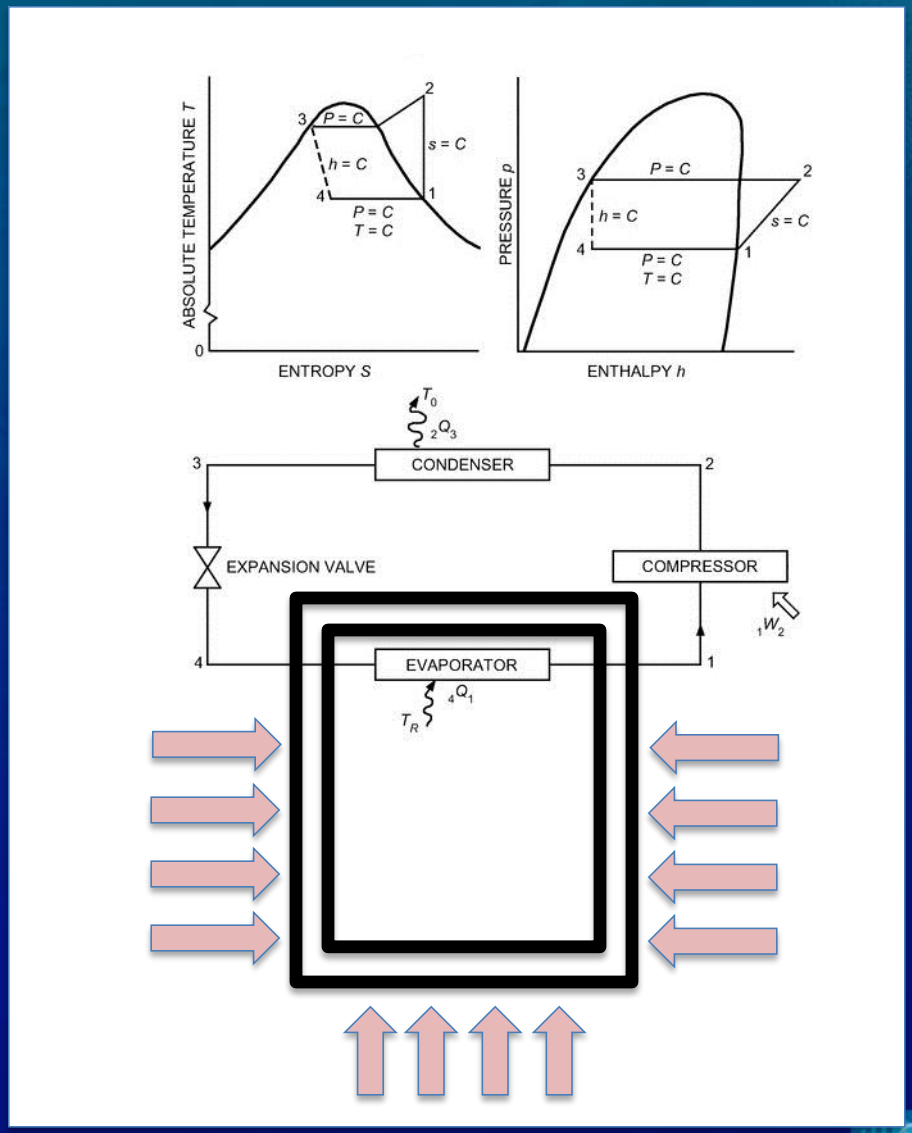
Historical Trends in Energy, Size, & Price



With permission from the Appliance Standards Awareness Project

Refrigerator Operation

- Insulated compartment maintaining cold temperature
  - Heat transferred from ambient through insulated walls
  - Evaporator removes heat from compartment
- Intermittent operation of cycle to maintain proper balance
  - Power input through compressor
- Vapor compression cycle
  - $COP_{carnot} = \frac{T_L}{T_H - T_L}$



What Influences Energy Consumption?

- Compressor, motor, and fan(s) efficiency
- Insulation
- Size and shape/layout
- Free vs. forced convection
- Defrost
  - Type
  - Frequency
  - Mechanism
- Operating conditions
  - Ambient and Internal temperatures
  - Air flow in and around unit
- Human interaction
  - Introducing warm foodstuffs
  - Opening doors (introducing warm, moist air)
- Control type and logic
- Ancillary functions

Key Attributes of Rating Method

- Measurement results using the test method must be repeatable and reproducible
- Results should characterize the energy consumed to maintain operating conditions over a period of time
- Ideal measurement results would be representative of field operation
- Minimal test burden

Test Method Objectives

- Measure energy consumption and compartment temperatures over a series of repeatable events
  - Fixed ambient temperature and air currents
  - Fixed control settings
  - Characterize and appropriately weight influence of regularly occurring functions (defrost, anti-sweat, etc.)
- Internal compartment temperatures are the performance target but user can only control set point
  - Repeat test at different set point(s) and interpolate to bound target temperatures

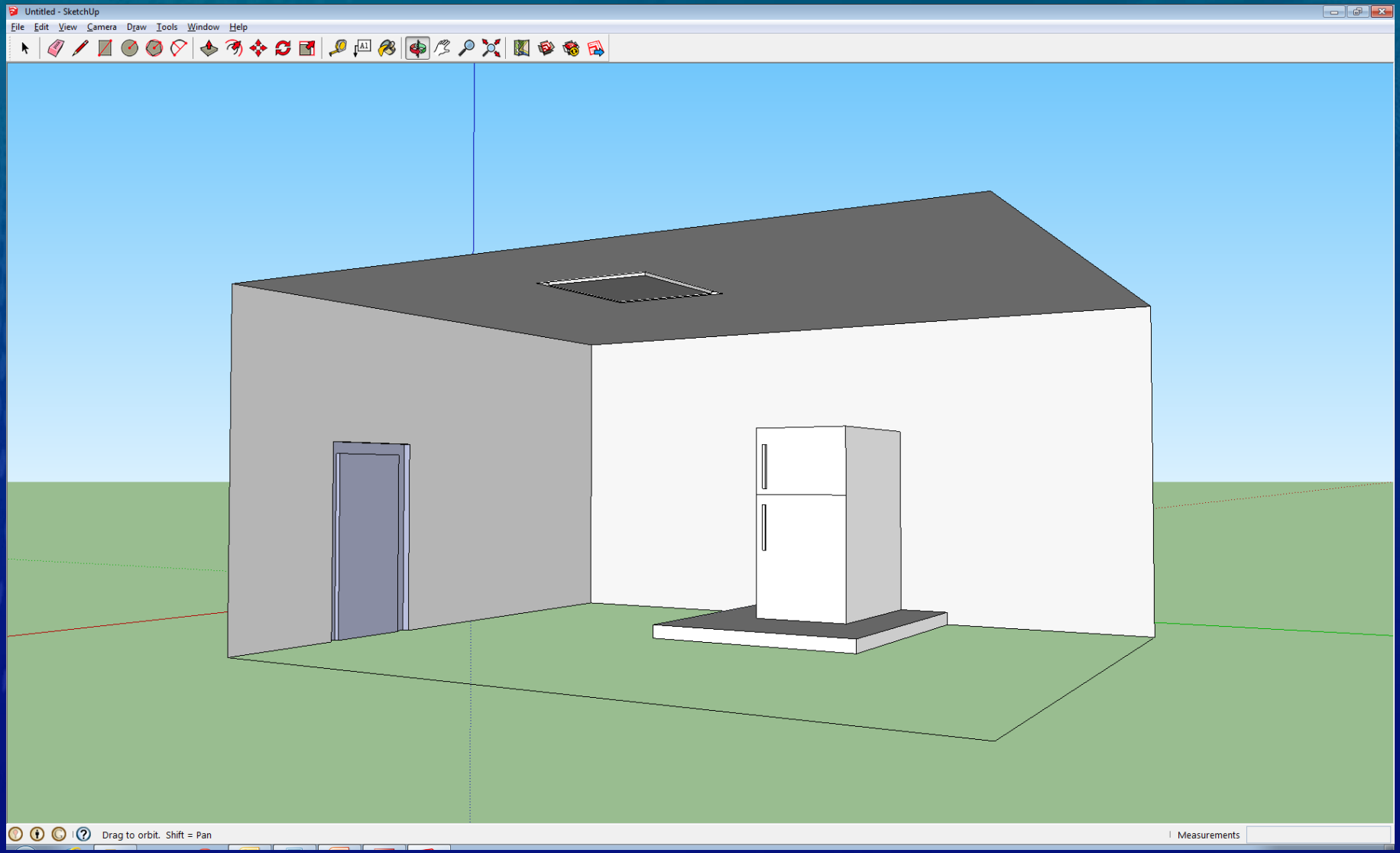
Considerations

- Different appliances have different functions
- The U.S. currently uses 42 product categories
  - Intended compartment temperature(s)
  - Configuration (single compartment, SBS, top mount, upright, etc.)
  - Defrost type (manual, auto, partial)
  - Other attributes
- Allowable energy consumption based on the internal adjusted volume of the product
  - Max energy = C1*(adj. volume) + C2
  - Constants vary by product type

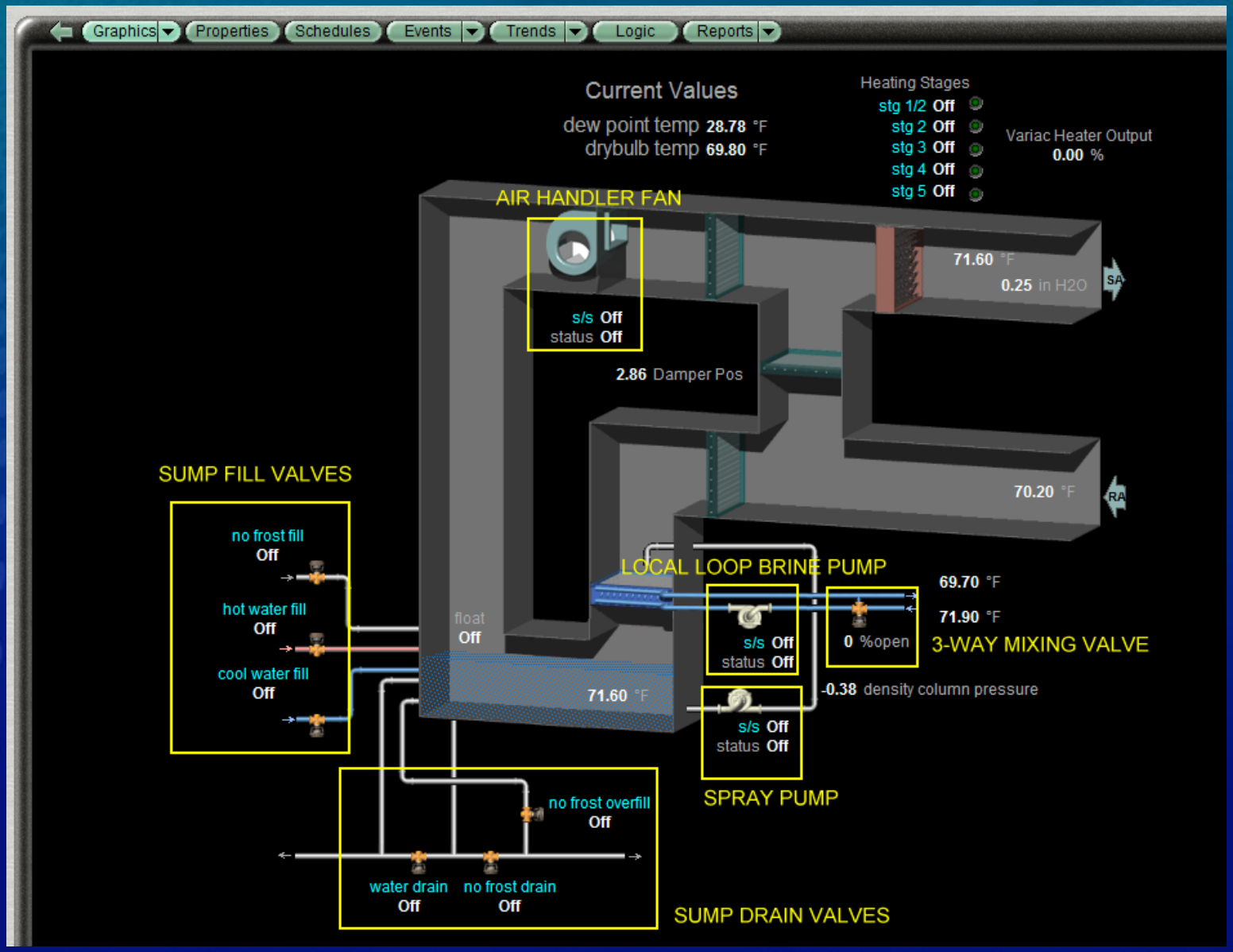
Test Setup

- Environmental chamber
  - Air temperature 32.2 ± 0.6 °C measured 25 cm from each center
  - Vertical gradient < 0.9 °C/m
  - Air currents < 0.25 m/s
- Conditioned power supply 115±1V, 60 Hz
- Watt-hour meter/signal analyzer
- Data Acquisition system
- Shield from radiation
  - Platform, walls, other units in chamber

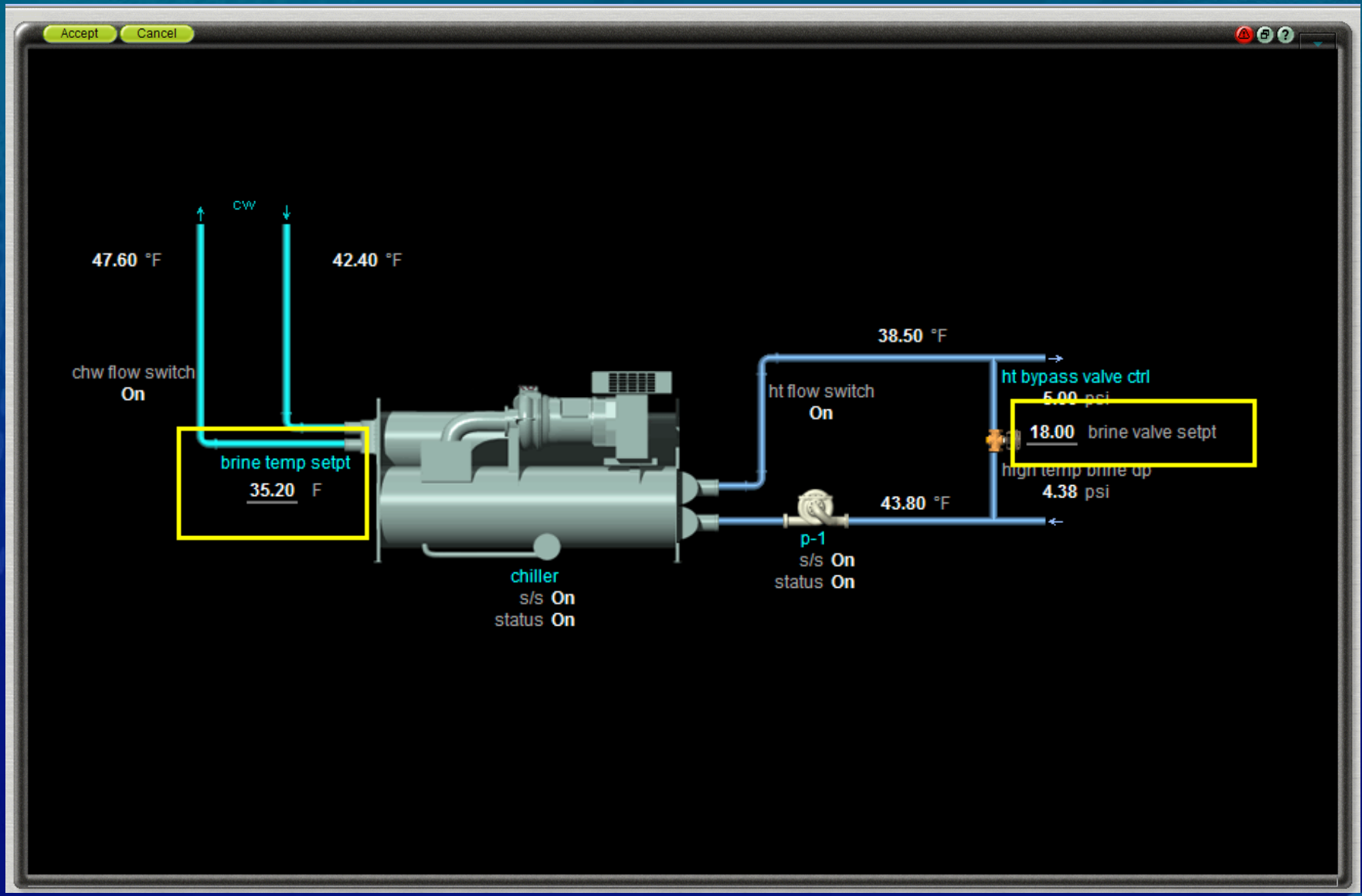
Environmental Chamber



Environmental Chamber



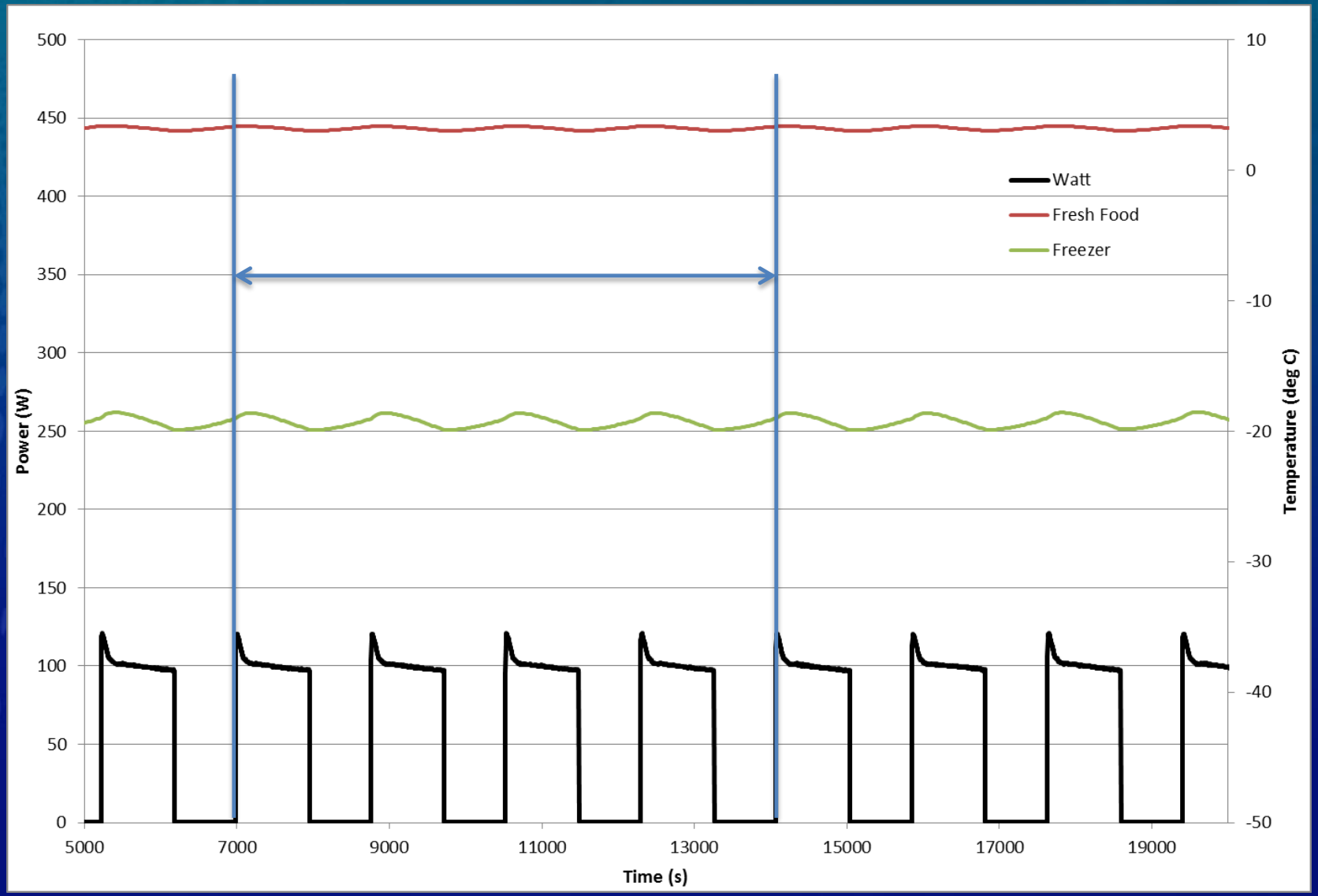
Environmental Chamber



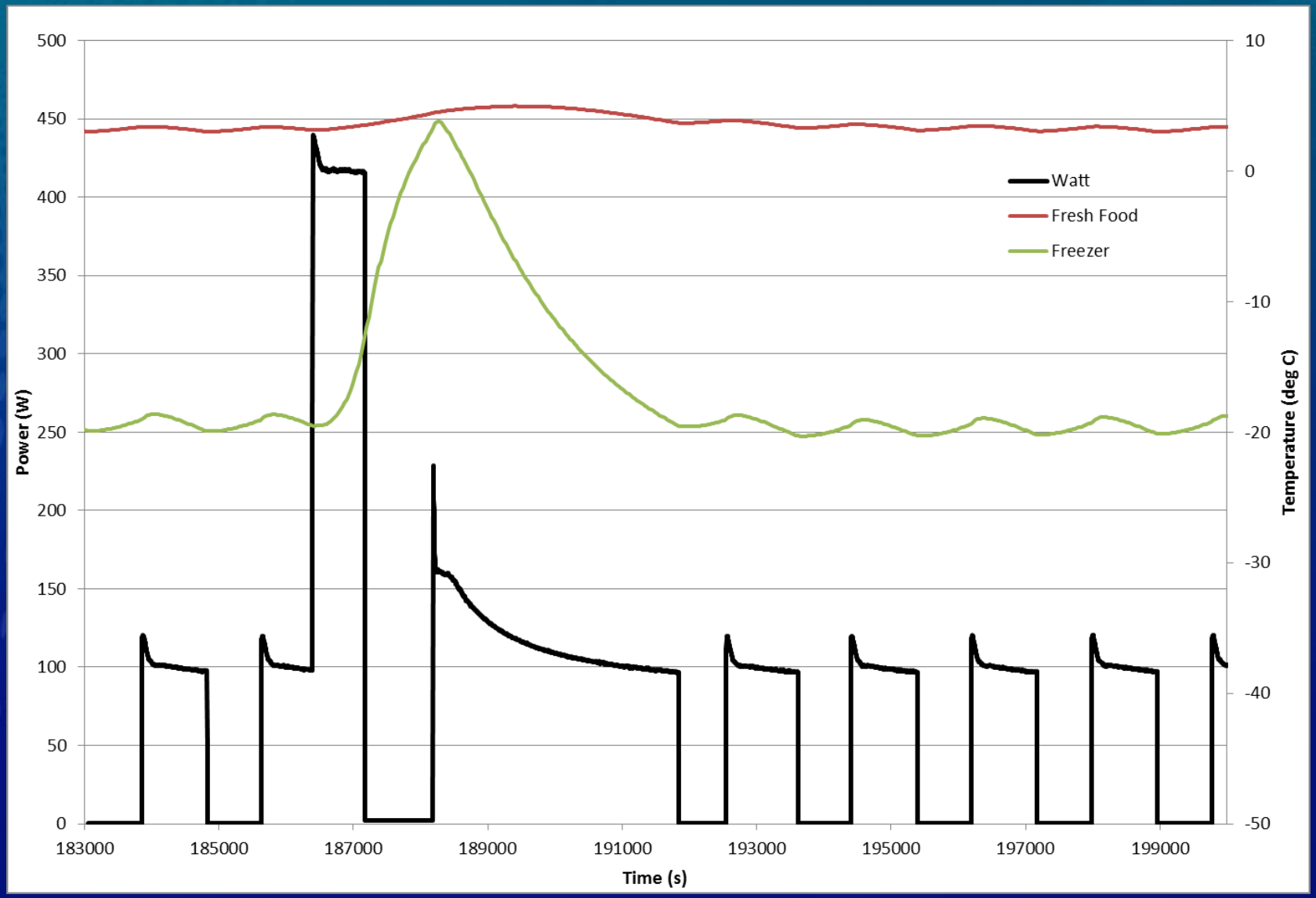
Test Setup – Internal Conditions

- Weighted thermocouples in cold compartments
  - Quantity and exact location dictated by several factors
- Unloaded compartments
- Median and warm/cold temperature settings for each compartment
- Steady state
  - Based on stability and repeatability of operational cycles

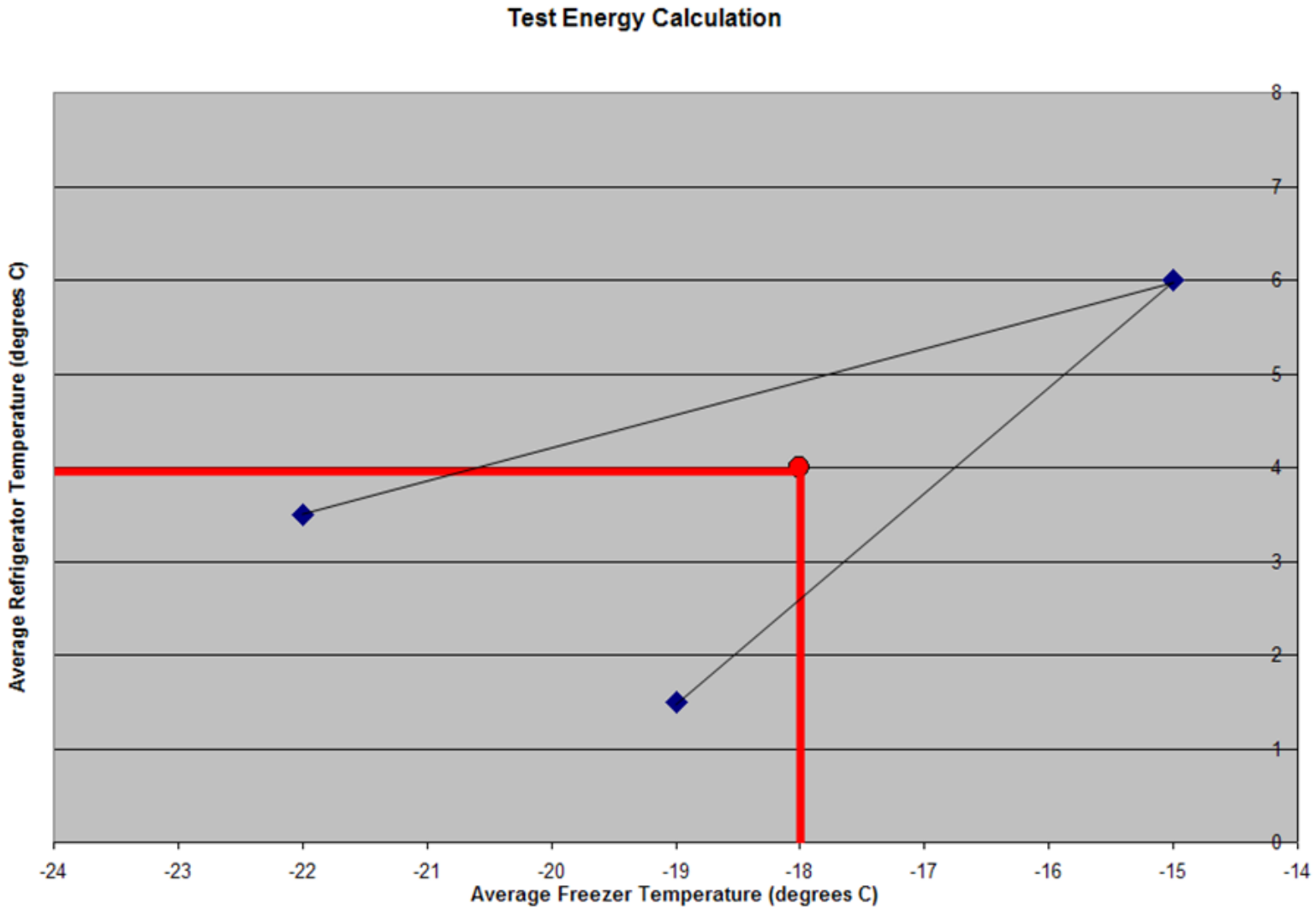
Typical Steady State Data



Defrost and Recovery



Interpolation



Other Considerations

- May not be able to achieve desired temperatures with controls
- Roll bonded evaporators remove heat via conduction therefore cannot use air temperature
  - Standard test package loading required
  - Careful placement to achieve repeatable test
  - Thermal ballast requires long test periods
- Inverter-driven, variable speed units will operate at part load conditions 100% of the time
- Units with independent compartment controls
- Dual compressor systems
- Others…

Circumvention

- Critical to integrity of program
- All tests in use are bound to fixed conditions that may be atypical for field use
  - Closed door, 32.2°C, empty compartment, etc.
- Most countries that regulate have seen products that attempt to circumvent the test procedure
  - If all test conditions all met – operate in low power mode
- Recent global efforts have focused on ensuring proper verbiage that defines and prohibits circumvention
  - Now included in U.S. (AHAM), AUS/NZ, IEC, and others

Summary

- Measurement based ratings and progressively stringent regulation has driven energy reductions since the 1970s
  - Compressors, insulation, controls, etc.
- Measurements require stable environmental chambers and some basic instrumentation
- Repeatable and reproducible test results
- Flexibility to consider different sizes, types, configurations, features, and use