May 7th, 2021

AC/HP Test Methods Investigative Testing

REQUEST FOR FEEDBACK: PHASE 2 PRELIMINARY FINDINGS

Phase 2 Preliminary Findings: Request for Feedback

- Phase 2 Overview
  - Objectives
  - Investigative Test Overview
- Phase 2 Request for Stakeholder Feedback
  - Questions for Stakeholders
  - Background Information and Preliminary Findings
- Next Steps

Investigative Testing Overview

Investigative Test Plan Objectives

Apply Load-based test concepts to various applicable existing methods of test

→

Evaluate test facility and test unit control responses in equilibrium and transient states (not including defrost)

→

Investigate influence of control inputs, test unit control settings, equilibrium approach techniques, instrument response and method of test agreement

1. What we want to do with the test plan is incorporate all the feedback from the forums while applying these load-based concepts to a range of existing methods of test.

2. Since the existing methods of test typically look for equilibrium, we'll be evaluating the factors that effect the test unit and test facility from attaining equilibrium. We also want to evaluate the response lag when the equipment is in transient states (e.g. RTD vs TC, what happens in the airflow measurement apparatus when the fans cycle off and potential best practices for quickly responding to operational state changes).

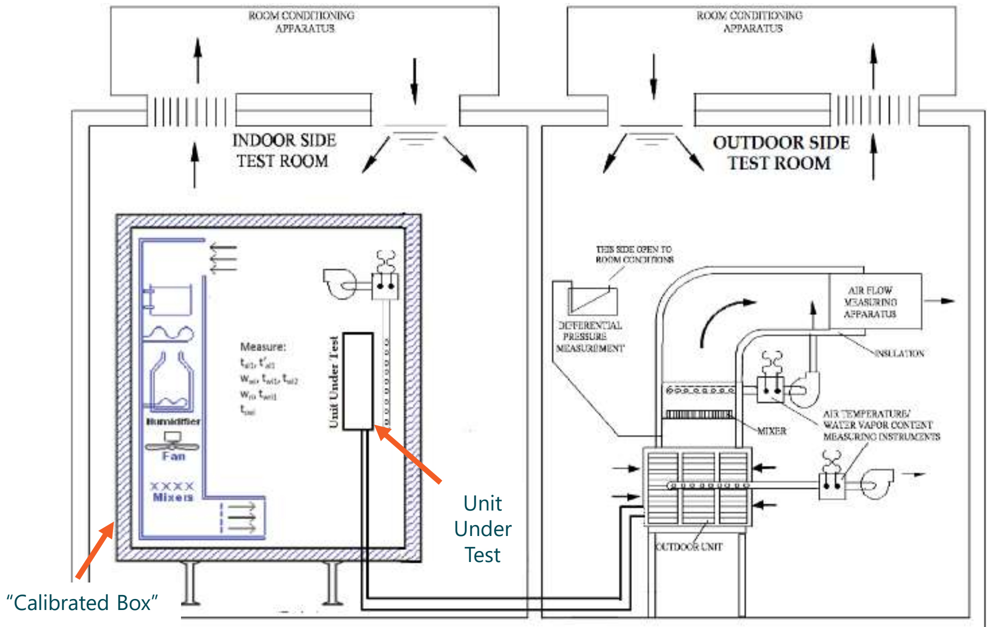
3. Our goal is to systematically attack each of the prioritized key issues identified in Phase 1 and investigate each issues unique influence on the tested units, the magnitude of its impact and develop proposed solutions to feed into Phase 3 – Test procedure development

Test Units and Method of Test Overview

Test Unit	Nominal Capacity	Configuration/Indoor Arrangement	Test Methods
A	• 15,000 Btu/h	• Single Split; Air Source Heat Pump • Non-ducted blower coil (wall mount)	• Indoor Room Calorimeter – Primary • Outdoor Air Enthalpy – Secondary • Indoor Air Enthalpy – Limited validation
B	• 24,000 Btu/h	• Single Split; Air Source Heat Pump • Non-ducted blower coil (wall mount)	• Indoor Room Calorimeter – Primary • Outdoor Air Enthalpy – Secondary • Indoor Air Enthalpy – Limited validation
C	• 36,000 Btu/h	• Single Split; Air Source Heat Pump • Ducted blower coil	• Indoor Air Enthalpy – Primary • Refrigerant Enthalpy - Primary

Since the scope of the project was updated to include heating, the units selected for this investigation are all variable speed, single zone split system heat pumps. Two units are non-ducted (high-wall mount) and the third is a ducted (conventional static) indoor blower. The range of test methods include Indoor room calorimeter, Indoor air enthalpy, outdoor air enthalpy and refrigerant enthalpy and each tested system will have a primary and secondary measurement for at least the full load in heating and cooling.

Non-ducted Unit Method of Test



- Hybrid of existing, well defined methods of test
- **Calorimetric method:** Modified psychrometric room to incorporate a **calibrated box on the indoor side**.
- **Outdoor Air Enthalpy** used for energy balance confirmation at full load in cooling and heating modes.
- **Indoor air enthalpy:** for validation of a limited number of test points.

Non-ducted unit test sequence*

Box Calibration
(Per ASHRAE 16)

Balance Tests for measurement validation

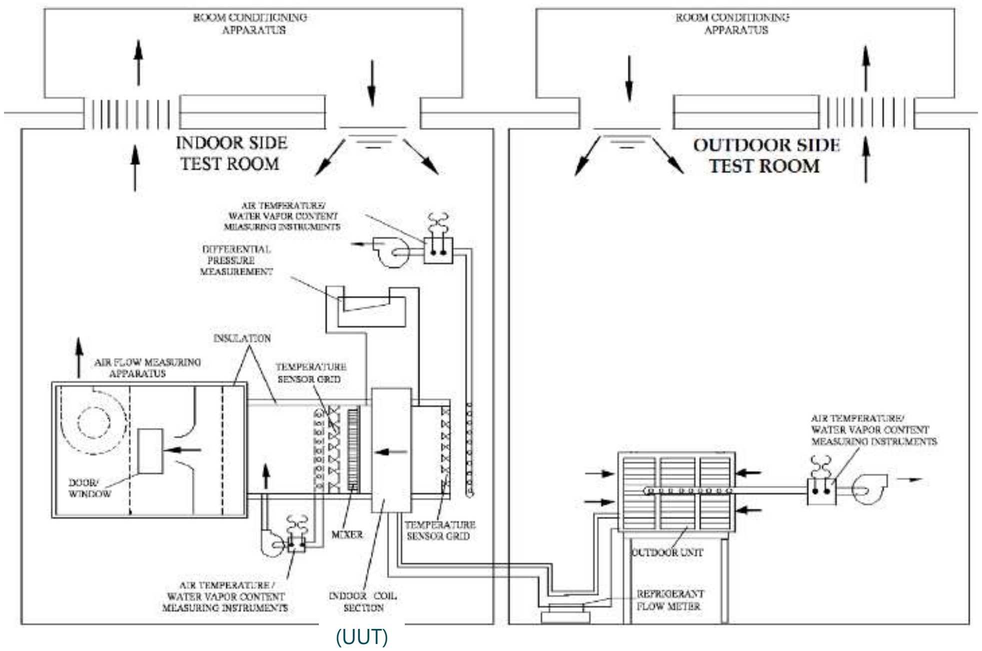
- Sensible Cooling
- Sensible & Latent Cooling
- Heating

Planned Performance Tests

- 8 Cooling
- 5 Heating
- 4 Dehumidification
- 3 Eco Cool
- 2 Eco Heat
- 2 Simulated load

* Detailed Test points are included in the Appendix

Ducted Unit Method of Test



- **Standard psychrometric facility**
- **Indoor Air Enthalpy** primary method
- **Refrigerant Enthalpy** used for energy balance on all tests achieving equilibrium
  - Expansion device located in the indoor unit which allows for proper refrigerant flow measurements
- Evaluate transient shifts and impacts comparing steady instruments to transient instruments on the air side as well as refrigerant enthalpy.

Ducted unit test sequence*

Validation Tests

- Control off-set
- Control dead band determination
- SC targets

Balance Tests for measurement validation

- Sensible & Latent Cooling
- Heating

Planned Performance Tests

- 8 Cooling
- 5 Heating
- 4 Optimized
- 2 Cyclic
- 3 CVP

* Detailed Test points are included in the Appendix

* Balance test excluded (refrigerant enthalpy on all tests)

Investigative Testing Stakeholder Feedback

Questions for Stakeholders

- Q1: Is there a consensus preference between Controls Verification Procedure (CVP), target compensation load or simulated use test?
- Q2: If target compensation is preferred, what is an allowable increase in tolerance?
- Q3: What is an acceptable test burden increase (in test time)?
- Q4: Can the test method be rating procedure agnostic?

Explore each question in depth on following slides.

Q1: What is the preferred test concept?

Dynamic load response / Simulated Use Test

- Utilizes a continuously variable increasing or decreasing load imposed on the unit under test to allow the unit's native controls to respond to the dynamic load
- Portions of CSA EXP-07 and AHRI 1230 CVP

Target compensation load

- Utilizes a stable load being imposed on the unit under test to allow for system control response to react and ultimately achieve a balanced steady-state condition
- Portions of CSA EXP-07 and EN 14511 with BAM/RiSE load-based testing modification

Controls Verification Procedure

- Utilizes a continuously variable increasing or decreasing load imposed on the unit under test to allow the unit's native controls to demonstrate viability
- AHRI 1230 CVP

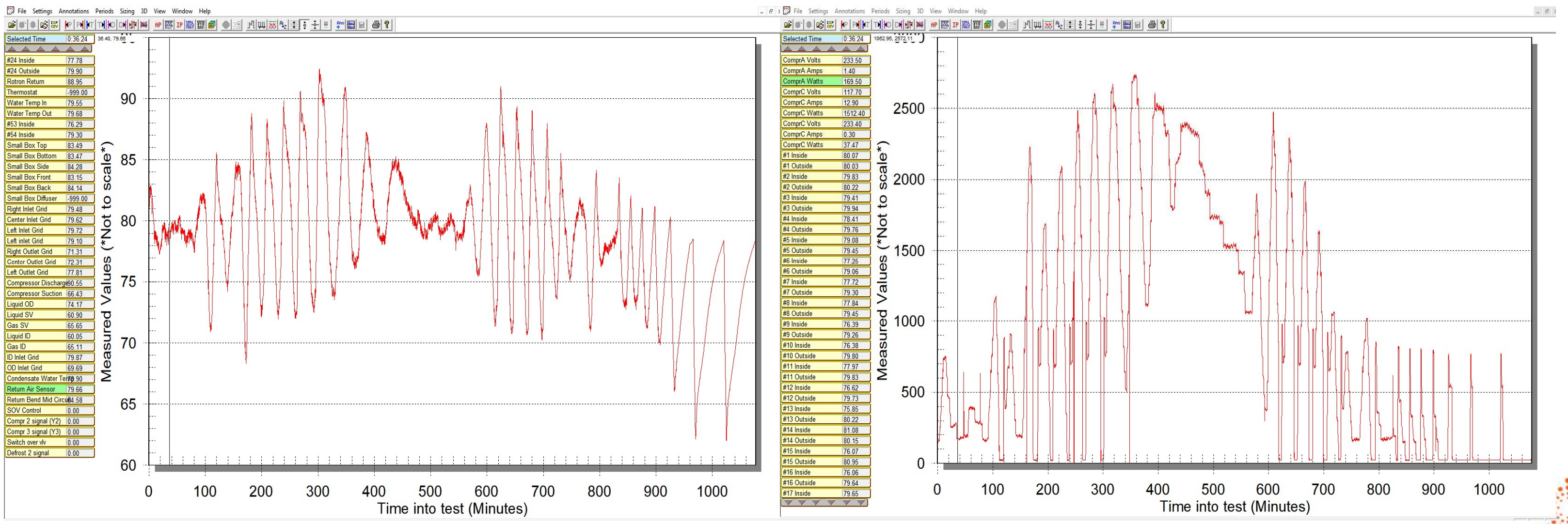
Q1: What is the preferred test concept?

Polling during outreach last year showed that the group preferred a target compensation load test concept. Is that still the case?

Test Concept	Strengths	Weaknesses	Additional Burden
Dynamic load response / Simulated Use Test	Allows for observation and validation of controls behavior and unit operational ranges	Less favorable in measuring heating/cooling load performance due to difficulty in repeatability/ reproducibility of test results	Unknown
Target compensation load	Provides some benefit of native control since compressor speeds are not locked during testing. Better repeatability/ reproducibility than dynamic load response	More controlled nature of test conditions may demonstrate less real-world controls response	60% to 250% increase
Controls Verification Procedure	Can test controls response to dynamically changing loads	Not suitable for direct measurement of performance	25% to 40% increase

Q1: Dynamic/Simulated use test concept?

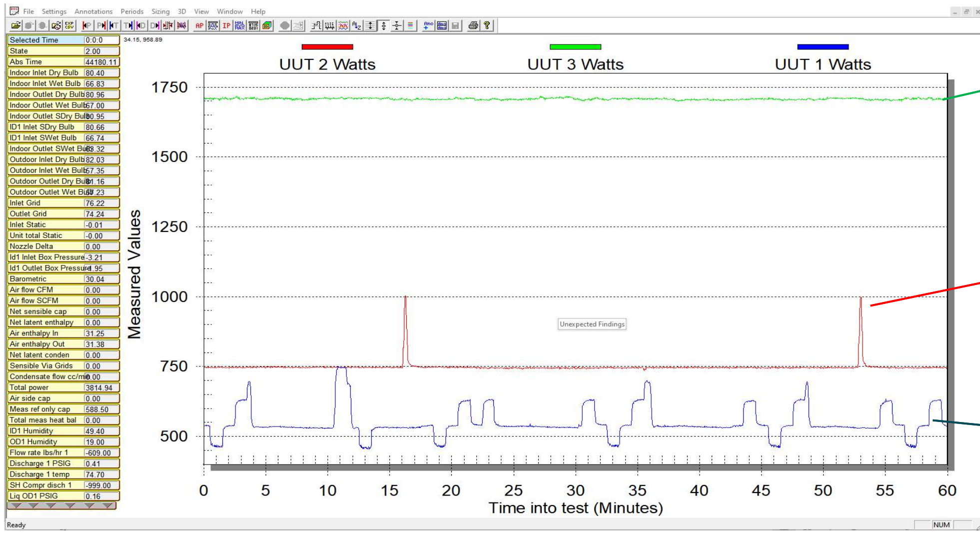
Dynamic/Simulated use test resulted in large temperature swings measured at the return air sensor using a steadily increasing/decreasing dynamic load.



- The calorimetric approach will require equilibrium to be achieved to trust the calculations.
- The transients of the test room power, moisture injection and room uniformity have a lead/lag relationship with each other as well as the unit response.
- This interaction is dependent on the size, thermal mass, controllability of the moisture injection and airflow distribution patterns in the box.

Q1: Target Compensation Load test concept?

Target Compensation Load test had varying levels of success.



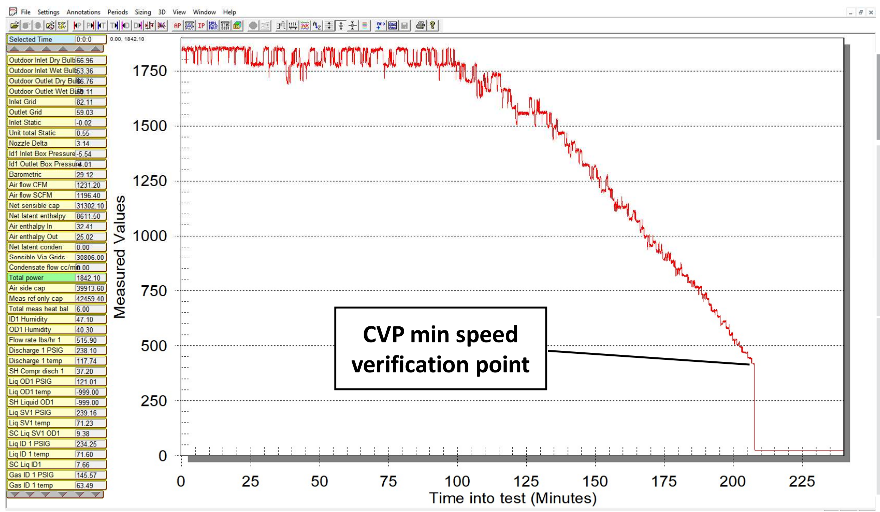
Unit 3: Controls behaved as anticipated

Unit 2: Unexpected Oil Return with otherwise anticipated controls

Unit 1: Aggressive Temperature Controls

Q1: Controls Verification Procedure test concept?

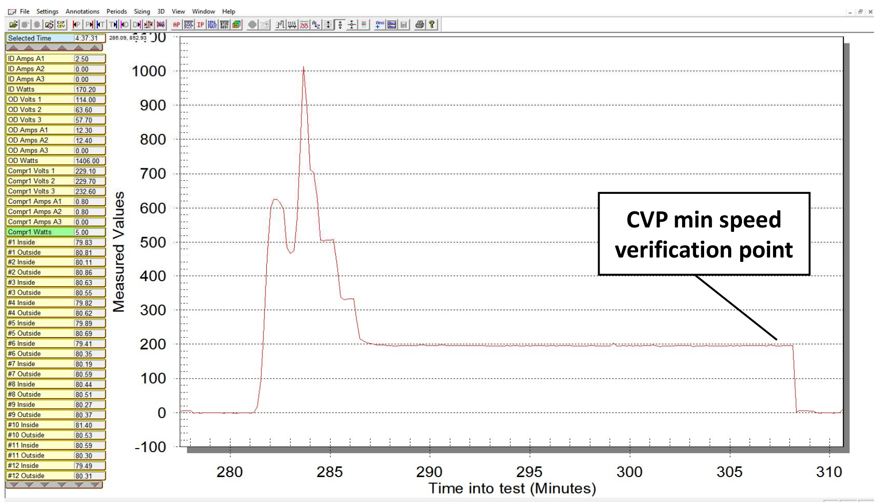
Psychrometric controls verification procedure for validating minimum compressor power, capacity and instantaneous EER successful at different loads. (3-4 hours per CVP)



		Capacity	Power	EER	% Diff
Med Temp Min Load	CVP	13378	524.64	25.67	0.54%
	SS	14004	552.20	25.99	
Low Temp Min Load	CVP	17645	457.04	38.61	6.16%
	SS	14672	357.99	40.99	

Q1: Controls Verification Procedure test concept?

Calorimetric controls verification procedure for validating minimum compressor power, capacity and instantaneous EER successful at different loads. (3-4 hours per CVP)



		Capacity	Power	EER	% Diff
Med Temp Min Load	CVP	5483	195.61	28.03	1.58%
	SS	5590	196.28	28.48	
Low Temp 2/3 Load	CVP	13503	635	21.26	12.19%
	SS	13890	573.77	24.21	

In the calorimetric room test, the CVP was more difficult due to sliding thermostat offsets between fan speeds (shown in Table at right).
See appendix for low temp 2/3 chart

Q1: What is the preferred test concept?

Recommendation:

Compensation target load is recommended if increased tolerance and burden is acceptable.

- Provides benefit of native control since compressor speeds are not locked during testing.
- Better repeatability/ reproducibility than dynamic load response.
- Poll responses during Phase 1 outreach indicated a preference for this approach.
- BUT Requires an increase in allowable tolerances.

Controls Verification Procedure is a viable path to consider

- Preferred if increased tolerances and/or burden are not acceptable.

~~Dynamic load response test – not recommended~~

- ~~Not repeatable in laboratory setting.~~

Question: Should a compensation target load-based test approach be developed?

Additional Question: If target compensation load is preferred, should transient tests be included or would a steady-state test at the lowest achievable load suffice?

What we found:

- Dynamic/Simulated use test is heavily dependent on the size, uniformity and thermal lag of the test chamber.
  - This would require normalization between test chambers
  - Not recommended
- Target Compensation Load is the preferred test concept assuming:
  - Wider test condition tolerances to allow for coarse unit set point adjustments is acceptable
  - Tighter test operating tolerances to allow for varying test unit control aggressiveness
  - Higher statistical uncertainty is acceptable
  - Transient cycling operation is mitigated by using the lowest achievable stable load.
- Control Verification Procedures are the preferred test concept assuming:
  - CVP is expanded to include any rating point
  - Tighter uncertainties are required for certification/regulatory activities and wider “pass/fail” tolerances apply for individual rating point outputs (e.g. capacity, power, SHR, EER)

Q2: Can allowable tolerances increase?

Background:

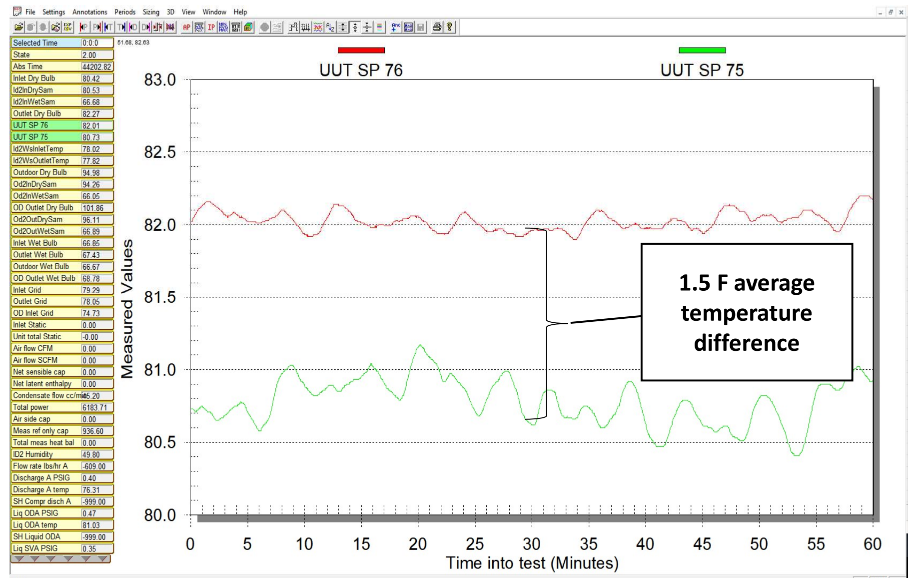
- Typical industry tolerances for test result repeatability (~2 %) and reproducibility (5%).
- Driven by instrumentation, test operating/condition tolerances and manufacturing tolerances.

- Instrument tolerances are in the appendix slides

Q2: Can allowable tolerances increase?
Test Condition Tolerance

What we found:

- Different systems have varying levels of discrete setpoint steps and control.
  - The test unit controls the temperature of the space in a target load compensation test.
  - A 0.5F condition tolerance will not be achievable for all systems.

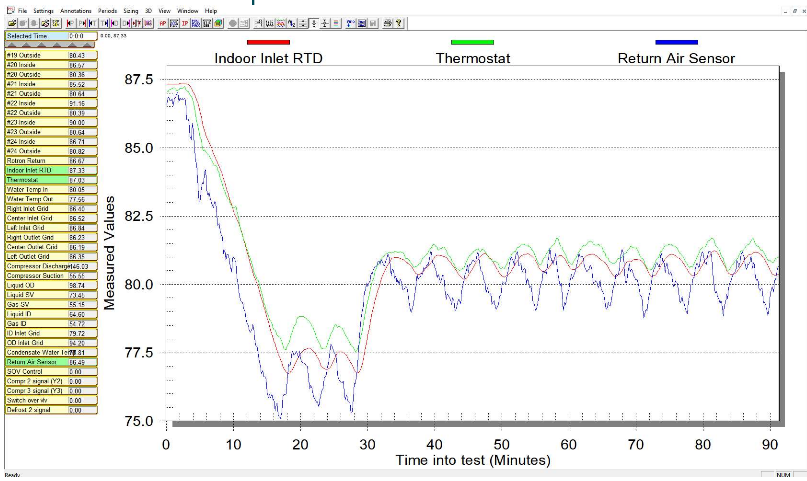


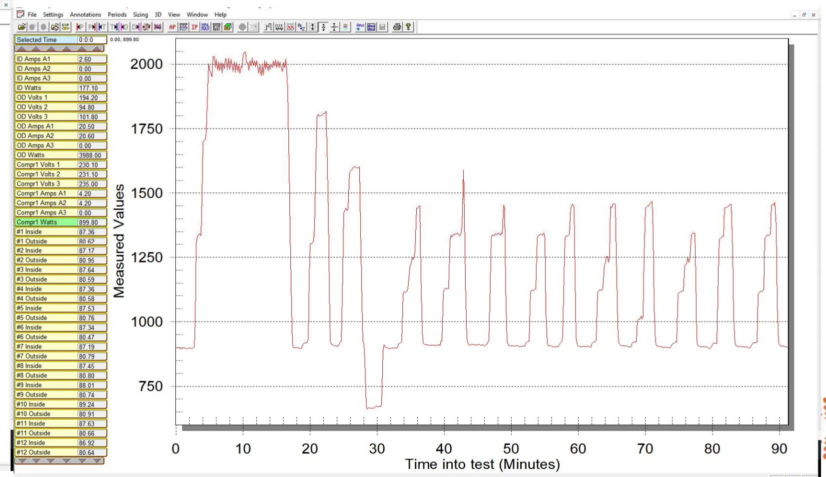
- Red and green lines show different runs at different set points.
- Assumption is that controller displays at °F but controls in °C.

Q2: Can allowable tolerances increase?
Test Operating Tolerances

What we found:

- Smaller dead-band ranges generally correspond to more frequent fluctuations in system output
- Units with aggressive temperature control loops will not achieve equilibrium with a fixed load if the control inputs exceed the dead-band.



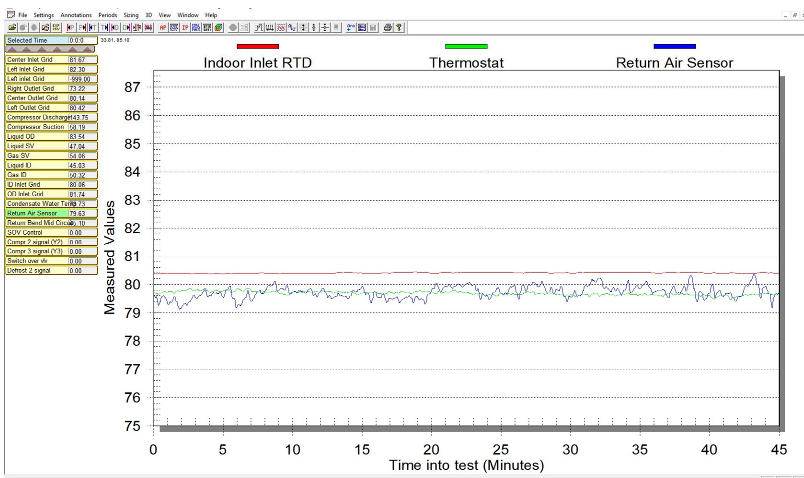


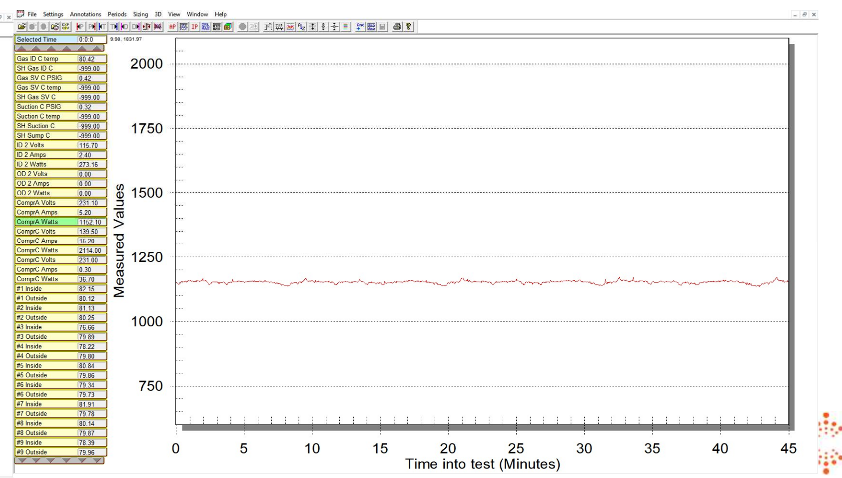
- Calorimetric test with a constant load injection to the box.
- Sensible box load was stable but the coil temperature swings from 42.6 – 58.3, which drove wet bulb temperature instability.

Q2: Can allowable tolerances increase?
Test Operating Tolerances

How we addressed:

- The same unit as shown in previous slide achieved equilibrium following test facility control tuning.
- The injected load was allowed to vary within 3% to maintain tighter operational tolerances

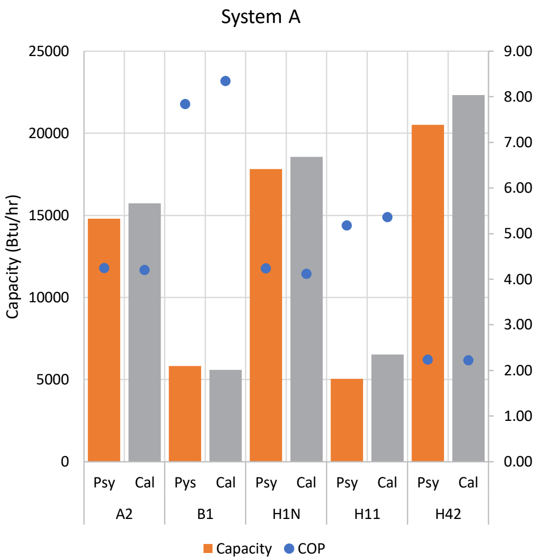


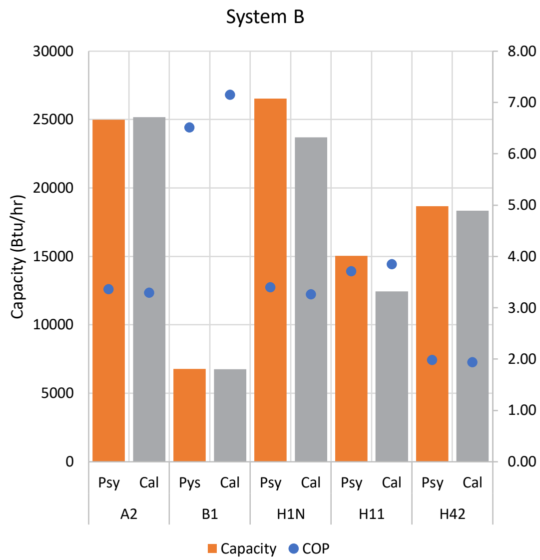


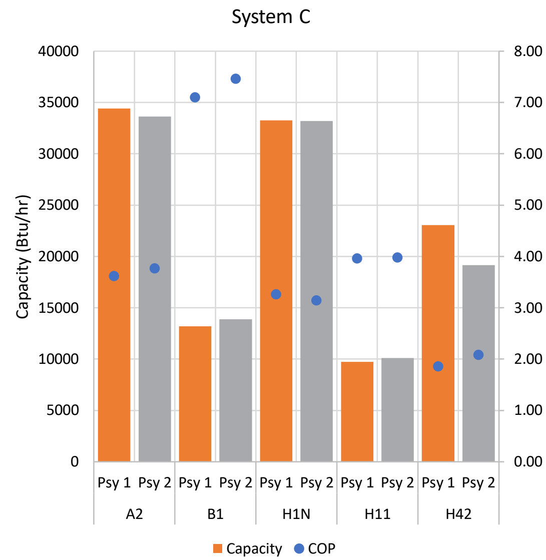
Key takeaway: There is a high probability that test lab control upgrades would be required to handle the various test unit control schemes. 3% was the number that worked out for this unit but will likely vary for different units.

- Units with humidity sensors to control coil temperature will require additional adjustments during the pre-equilibrium period. The process of adjusting both dry bulb and wet bulb temps (or target inlet humidity ratio) was quite burdensome as the steam plate temperature regulation impacted the sensible contribution as well.
- A similar approach to the CSA load adjustment strategy was employed without the convergence check and a third loop of dry bulb control was employed that looked at the previous three cycle trends to predict the setpoint offset adjustment updated each second.

Q2: Can allowable tolerances increase?
Test Facility Comparison







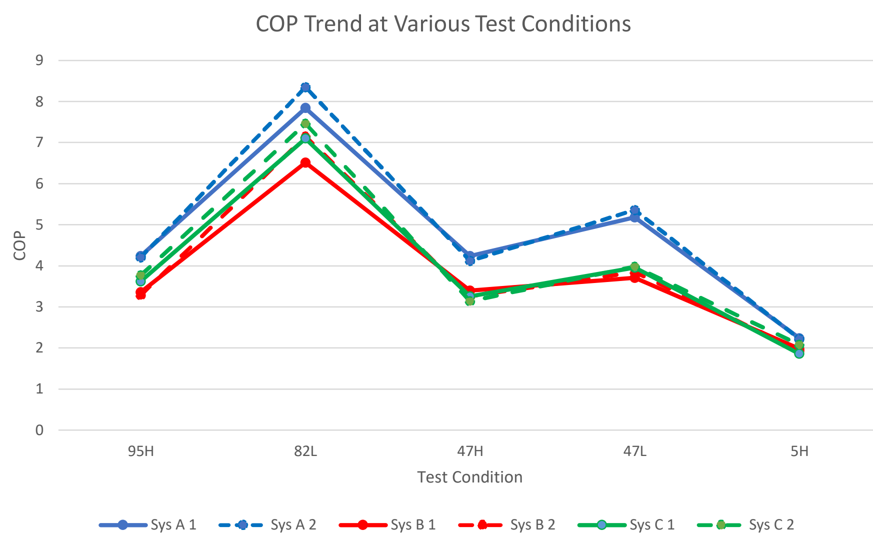
*Refer to speaker notes for Test conditions

Test comparison between two test facilities on the same unit.
System A shows Psych room (orange) vs Calorimetric (gray)
System B shows Psych room (orange) vs Calorimetric (gray)
System C –ducted unit shows Psych room 1 (orange) vs Psych room 2 (gray)
Refer to next slide for findings
*Test Conditions:
Cooling: A2: 95°F DB, Cooling Full Speed; B1: 82°F DB, Cooling Minimum Speed
Heating: HIN: 47°F DB, Heating Full Speed; H11: 47°F DB, Heating Minimum Speed; H42: 5°F Heating Full Speed

Q2: Can allowable tolerances increase?
Test Facility Comparison

What we found:

- Capacity varied by as much as 22.5%
  - Mostly driven by different minimum stable operating points
  - <6% at full load cooling
- COP varied by as much as 10.6%
  - COP trends as expected with higher capacity resulting in lower COP.
  - One exception is the median temperature minimum load test where the capacities were similar, and the COP were approx. 6% higher.



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Graph shows COP results for three separate systems (A, B, C) in two separate test facilities.

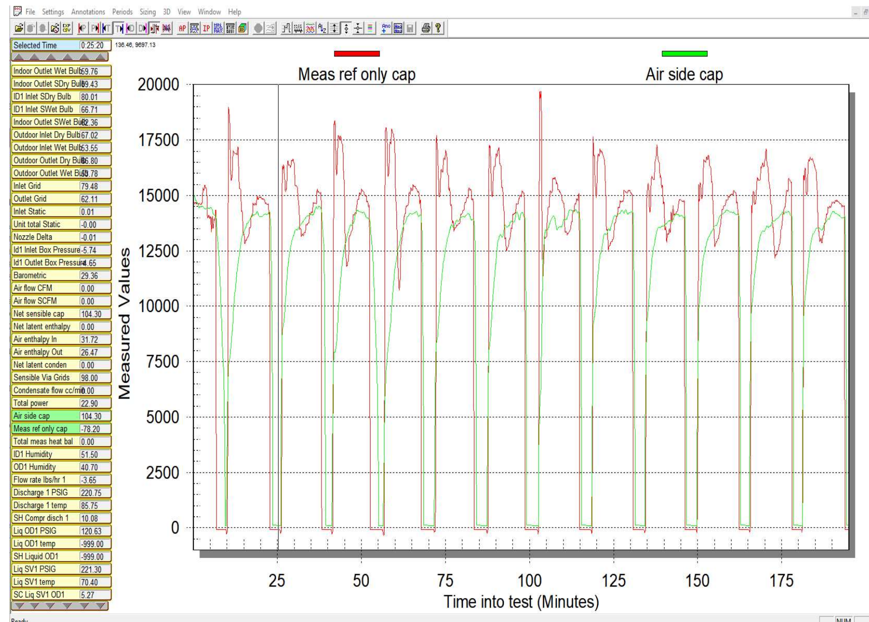
Q2: Can allowable tolerances increase? Repeatability with Transients

What we found:

- Inconsistent unit fan step control and missed "fan off" timing on the airflow measurement apparatus resulted in energy balance shifts of up to 28%.
- Refrigerant enthalpy method consistently performed between 4 and 11% higher than air enthalpy method

Future mitigation strategies:

- Address synchronization of unit/lab fans in test method
- Characterize measurement/instrumentation thermal mass
- Research and quantify contributing factors to energy balance shifts (e.g. instrument response, thermal mass, re-evaporation, etc.)



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Key takeaway: We don't yet trust measurements of cycling behavior, since lab control and measurement procedures can impact outputs.

See Cycle Convergence Comparison slide in appendix.

Q2: Can allowable tolerances increase?

Conclusions:

- Condition tolerance should likely double to allow for unit setpoint control discrete steps
- Operating tolerances must at least match unit dead band to achieve steady state
- Resulting Repeatability & Reproducibility (R&R) would also require increase
  - Likely 10-15% COP in allowable R&R required

Feedback: Is a 15% increase in R&R tolerance acceptable?

→ If not, need to use CVP method instead of target load compensation

Q3: Is there a maximum allowable test burden increase?

- A typical variable speed heat pump takes 60 hours to setup and test using manufacturer overrides.
- The investigative testing on two of the three units show between 36 and 90 hours of additional time for adaptive learning and test unit control characterization.

Question: Assuming a baseline test burden is 60 hours, is there a maximum allowable test burden increase considered acceptable to move to a load-based test procedure?

- Up to 15 hours (25% increase)
- Up to 30 hours (50% increase)
- Up to 60 hours (100% increase)
- Over 60 hours (Above 100% increase)

Q4: Can the test method be rating procedure agnostic?

Background:

- Rating procedures for domestic AC/HPs typically specify three things:
  1. What to measure and how
  2. Specific points at which things are measured
  3. How collected data is combined into a calculated rating

- We propose to generate a test procedure that specifies the first two, but leaves the calculation and rating procedure to the local authorities to define
  - In addition, local authorities may choose to add extra rating points to better characterize local conditions.

Suggest test points could be cooling 65-115°F and heating 62-5°F.

Q4: Can the test method be rating procedure agnostic?

What we found:

- Various combinations of operation modes and functions were available on each test unit
  - **Operating Mode:** Auto, Cool, Heat, Fan Only
  - **Special Functions:** Dehumidification, Eco, Jet
  - **Fan Settings:** Auto, Hi, Med-Hi, Med, Med-Lo, Lo, Quiet, Energy Fan, Circulate
  - **Louver:** Swing Vertical, Swing Horizontal, Fixed 1-6/8 Vertical, Fixed 1-5 Horizontal
- Changing the mode/function of the unit did not always result in changes to operation. The only observed difference was the return air temperature indicated on the unit

Recommendation 1: Test units using heat only/cool only operating settings and auto* fan setting

- Heat only or cool only limits variability and keeps unit in consistent mode
- Auto fan lets unit adjust under its own controls

Recommendation 2: Allow optional test modes, ambient temperature, climate bins, and any additional test unit control settings to be set at the jurisdictional level.

Further Detail for Recommendation 1:

- For ducted units, recommend testing in auto fan.
- For ductless units tested in a calorimetric room and tested w/ target compensation load- recommend auto
- If ductless units are tested psychrometrically, recommend locking fan speed corresponding to the appropriate (high, med, low) compressor speed
- Auto does make the test harder/less repeatable but fixed speed settings do not make sense unless you're going to match it to the compressor level.

Next Steps

- Submit written response no later than **21 MAY, 2021**
- Send comments to:

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Mark Ellis
IEA/4E Operating Agent
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- Final Investigative Test Findings Report will be shared in July 2021

Appendix

Non-ducted unit test points

Test #	Test Name	Description	Method
1	Calibration	Box Calibration per ASHRAE 16 (25F)	Box Calibration
2	Balance 1	Sensible only maximum Cooling	Indoor Room Calorimeter/ Outdoor Air Enthalpy
3	Balance 2	Sensible and latent Cooling	Indoor Room Calorimeter/ Outdoor Air Enthalpy
4	Balance 3	Heating	Indoor Room Calorimeter/Outdoor Air Enthalpy
5	Cooling	Base/Default Cooling	Indoor Room Calorimeter
	5a	High temp (rated load)	Indoor Room Calorimeter
	5b	High temp (min load)	Indoor Room Calorimeter
	5c	Median temp (full load)	Indoor Room Calorimeter
	5d	Median temp (2/3 load)	Indoor Room Calorimeter
	5e	Median temp (min load)	Indoor Room Calorimeter
	5f	Low temp (full load)	Indoor Room Calorimeter
	5g	Low temp (2/3 load)	Indoor Room Calorimeter
	5h	Low temp (min load)	Indoor Room Calorimeter
6	Heating	Base/Default Heating	Indoor Room Calorimeter
	6a	High temp (rated load)	Indoor Room Calorimeter
	6b	High temp (min load)	Indoor Room Calorimeter

Test #	Test Name	Description	Method
	6c	Max temp (min load)	Indoor Room Calorimeter
	6d	Low temp (max load)	Indoor Room Calorimeter
	6e	Lowest temp (max load)	Indoor Room Calorimeter
7	Dehumidification	Dehumidification Mode	
	7a	High temp (rated load)	Indoor Room Calorimeter
	7b	Median temp (2/3 load)	Indoor Room Calorimeter
	7c	Median temp (min load)	Indoor Room Calorimeter
	7d	Low temp (min load)	Indoor Room Calorimeter
8	Eco Cool	Eco/Energy Save mode	
	8a	High temp (rated load)	Indoor Room Calorimeter
	8b	Median temp (2/3 load)	Indoor Room Calorimeter
	8c	Low temp (min load)	Indoor Room Calorimeter
9	Eco Heat	Eco/Energy Save mode	
	9a	High temp (rated load)	Indoor Room Calorimeter
	9b	Low temp (max load)	Indoor Room Calorimeter
10	Sim Use		
	10a	Cooling mode (load curve)	Indoor Room Calorimeter
	10b	Eco mode (load curve)	Indoor Room Calorimeter

Ducted unit test points

Test #	Test Name	Description
1	Control Validation	Control off-set/Control dead-band determination
2	Charge Validation	SC targets in both cooling and heating mode
3	Balance 1	Sensible and latent Cooling
4	Balance 2	Heating
5	Cooling	Base/Default Cooling
	5a	High temp (max load)
	5b	High temp (rated load)
	5c	Median temp (full load)
	5d	Median temp (2/3 load)
	5e	Median temp (min load)
	5f	Low temp (full load)
	5g	Low temp (2/3 load)
	5h	Low temp (min load)
6	Heating	Base/Default Heating
	6a	High temp (rated load)

Test #	Test Name	Description
	6b	High temp (min load)
	6c	Max temp (min load)
	6d	Low temp (max load)
	6e	Lowest temp (max load)
7	Optimized	Cooling Optimized Setting
	7a	High temp (rated load)
	7b	Median temp (2/3 load)
	7c	Median temp (min load)
	7d	Low temp (min load)
8	Cyclic	Cooling (sub-min load)
	8a	12 cycle test @ F1
	8b	12 cycle test @ B1
9	CVP	1230 Cooling CVP
	9a	High temp (rated load)
	9b	Median temp (min load)
	9c	Low temp (min load)

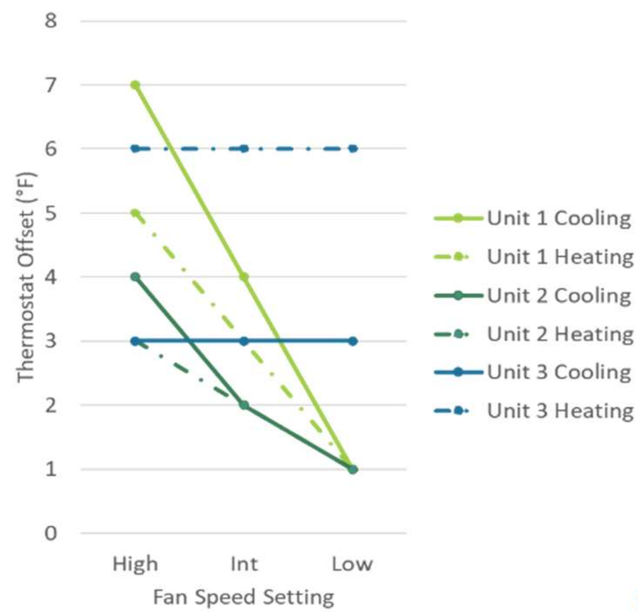
Operating and Condition Tolerances

Table4									
Test Tolerances: SI Units (I-P)		Test Operating Tolerance (Total Observed Range)				Test Condition Tolerance			
		Cooling	Non-Frosting	Heat with Frost[a]		Cooling	Non-Frosting	Heat with Frost[a]	
				Heat Portion	Defrost Portion			Heat Portion	Defrost Portion
Outdoor Dry-Bulb Temperature - ºC (ºF)	Entering	1.0 (2.0)	1.0 (2.0)	1.7(3.0)	5.6(10)	0.3(0.5)[b]	0.3(0.5)[b]	0.5(1.0)	N/A
Outdoor Wet-Bulb Temperature - ºC (ºF)	Entering	0.5 (1.0)	0.5 (1.0)	0.9(1.5)	N/A	0.2(0.3)[bd]	0.2(0.3)[b]	0.3(0.5)	N/A
Indoor Dry-Bulb Temperature - ºC (ºF)	Entering	1.0 (2.0)	1.0 (2.0)	1.7/3.0	2.2(4.0)[d]	0.3(0.5)[b]	0.3(0.5)[b]	0.5(1.0)	N/A[c]
Indoor Wet-Bulb Temperature - ºC (ºF)	Entering	0.5 (1.0)	0.5 (1.0)	N/A	N/A	0.2(0.3)[b]	N/A	N/A	N/A
Condenser Cooling Liquid Temperature - ºC (ºF)		0.3(0.5)	0.3(0.5)	N/A	N/A	0.1(0.2)[b]	0.1(0.2)	N/A	N/A
Saturated Refrigerant Temperature Corresponding to the Measured Indoor Side Pressure - ºC (ºF)		1.7(3.0)	1.7(3.0)	N/A	N/A	0.3(0.5)	0.3(0.5)	N/A	N/A
Make up Water temperature - ºC (ºF)		0.3(10)	NA	N/A	N/A	0.1(5.0)	N/A	N/A	N/A
External Resistance to Airflow - Pa(inches of H2O)	Ducted	12.5(0.05)	12.5(0.05)	N/A	N/A	N/A	N/A	N/A	N/A
	Non-ducted								
Electrical Voltage (% of reading)		2	2	2	N/A	N/A	N/A	N/A	N/A
Liquid Flow Rate (% of reading)		2	2	N/A	N/A	N/A	N/A	N/A	N/A
Nozzle Pressure Drop (% of Reading)		2	2	N/A	N/A	N/A	N/A	N/A	N/A

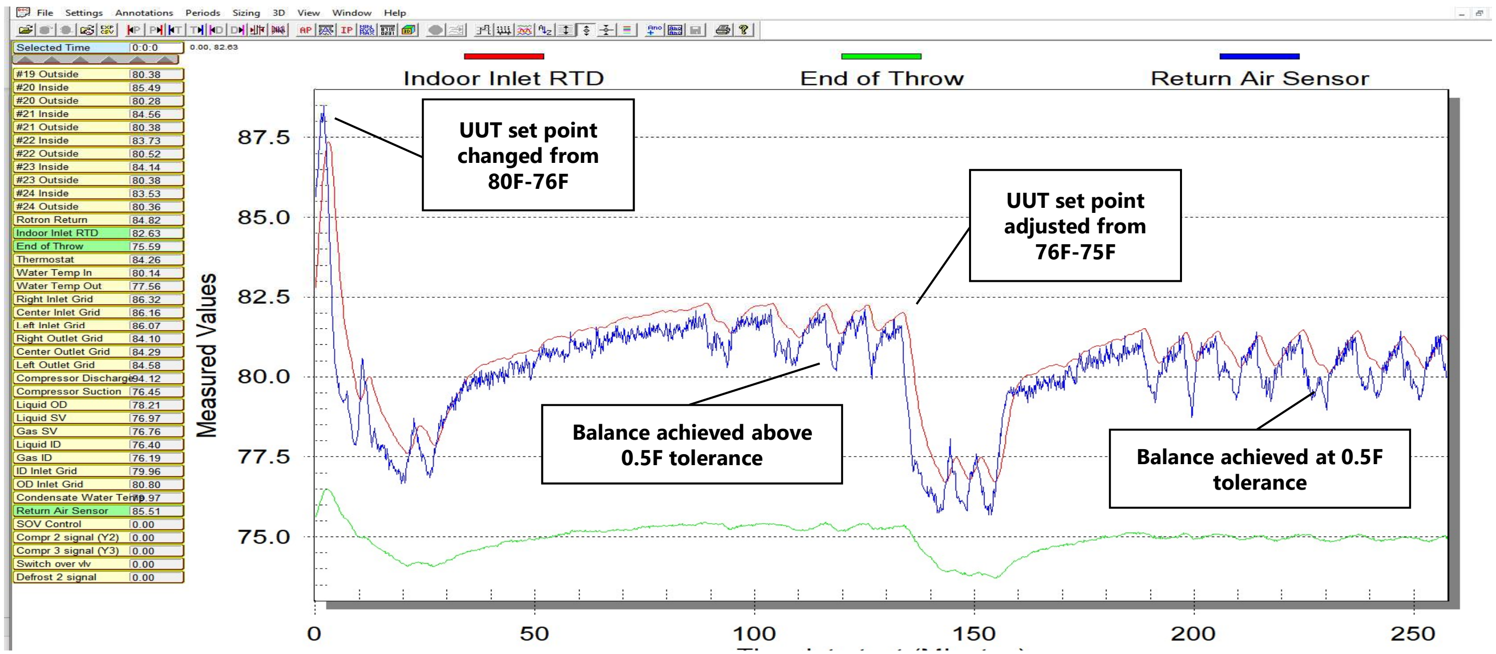
Thermostat Control

Temperature Sense Switching

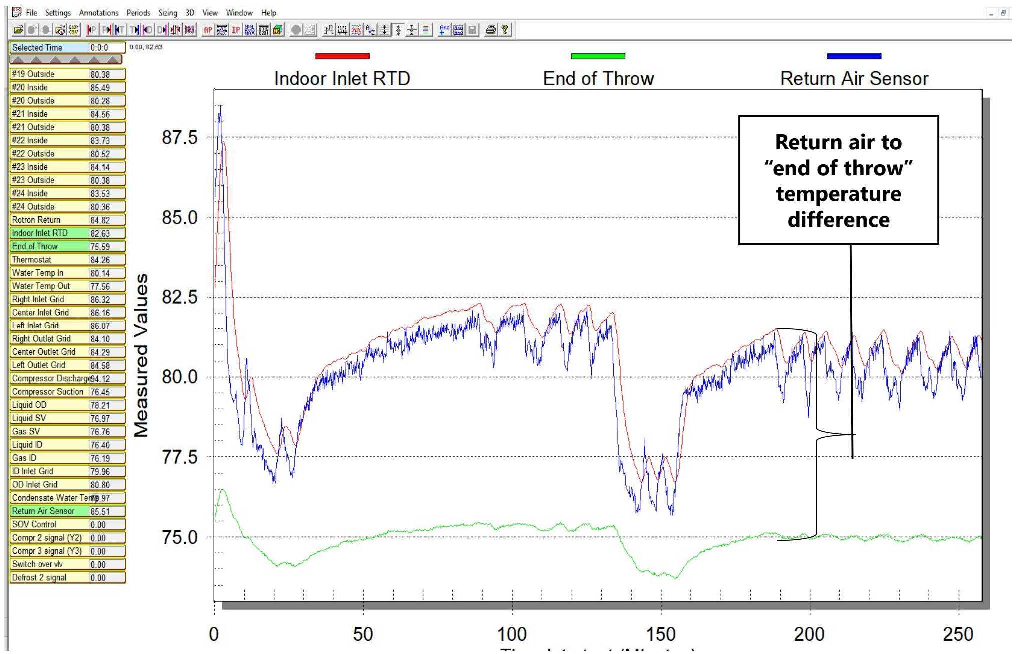
- System response is controlled via indoor unit return air thermistor, remote thermistor, or a wired thermostat
  - Unit 1 allowed return air thermistor, remote thermistor, or a combination of the two
  - Unit 2 only allowed return air thermistor
  - Unit 3 only allowed wired thermostat thermistor
- Thermostat set point offset/bias
  - Varied by unit and by test point
  - For units 1 and 2, set point offset/bias appears to vary by indoor fan speed, while unit 3 exhibited fixed set point offset
  - To adjust for variations in set point offset/bias, additional iterative runs were required (next slide)



Thermostat Offset/Bias Adjustment

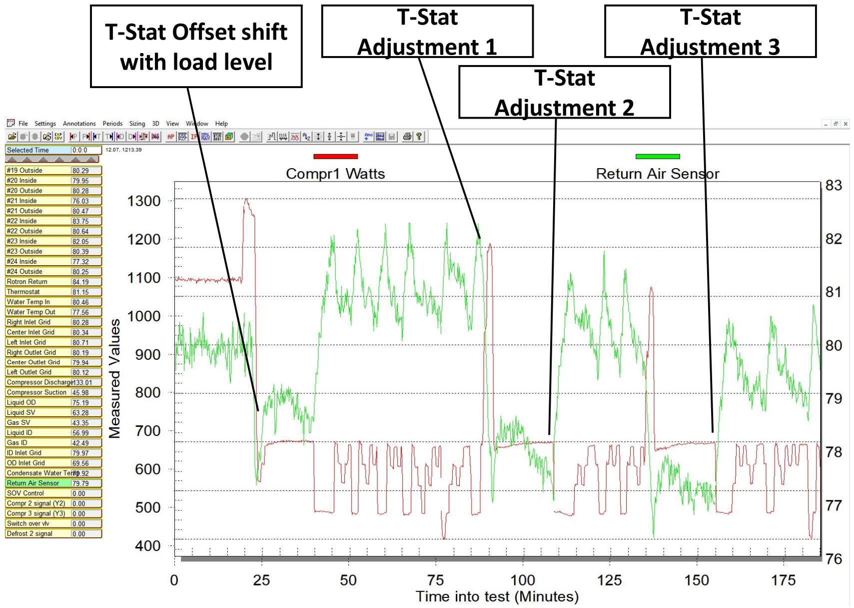


Thermostat Offset/Bias Adjustment



- Unit exhibited what is assumed to be "spot cooling control", i.e. the supply air temperature at the "end of throw" closely matches the unit setpoint
- After throw, air warms as it passes back through room to return air sensor
- Temperature difference between "end of throw" and return air sensor decreases as fan speed decreases

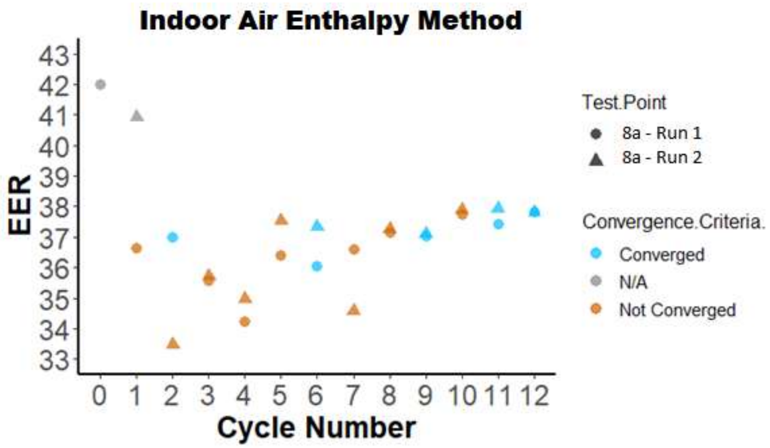
Calorimetric CVP (Load Ramp Down)

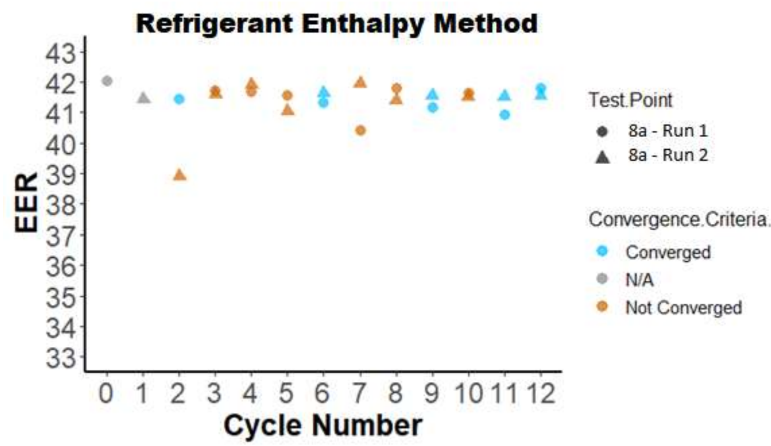


Calorimetric CVP with sliding T-stat offsets requires additional adjustment of the T-stat during the test to approach the target slow enough.

Cycle Convergence Comparisons

Convergence Criteria from CSA EXP-07 applied to two 12 cycle F1 tests on the ducted system. Both the air and refrigerant enthalpy methods were analyzed.





The indoor air enthalpy method showed more distribution and a larger spread of converged EER values.
The refrigerant enthalpy method performed consistently higher and aligned closely with steady-state EER.

Indoor Air Enthalpy Method converged average was 37.28 (1.90 EER spread)
Refrigerant Enthalpy Method converged average was 41.63 (0.63 EER spread)