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AC/HP Test Methods 2.0:

Phase 2 Findings Summary

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List of Acronyms

AC	Air Conditioner
AHJ	Authority Having Jurisdiction
AHRI	Air-conditioning, Heating, and Refrigeration Institute
ASHP	Air-source Heat Pump
Btu/h	British Thermal Units per Hour
°C	Degrees Celsius
COP	Coefficient of Performance (Watt/Watt)
CVP	Controls Verification Procedure
EER	Energy Efficiency Ratio (Btu/Watt)
°F	Degrees Fahrenheit
HP	Heat Pump
ISO	International Standards Organization
kW	Kilowatt
RA	Return Air
RTD	Resistance Temperature Detector
T-stat	Thermostat
UUT	Unit Under Test
W	Watt

Section 1: Introduction/Phase 1 Background

Residential air conditioner (AC) and heat pump (HP) manufacturers have increasingly introduced variable capacity, or "inverter-driven" units to the market, promoting them as the most efficient equipment available. However, the established AC and HP test procedures used for regulatory purposes around the world fail to capture the impact of the modulating native equipment controls, which have a critical efficiency impact in these variable capacity units. The modulating native controls are missed because current test methods require the compressor be locked at fixed speeds. While this locked compressor approach to testing yields a snapshot of performance at a particular set of conditions, it fails to capture the modulating nature of the native equipment controls, which have been shown to significantly impact efficiency of the variable capacity ACs and HPs. Multiple regions are developing new load-based methods for testing these products with the goal of ensuring test procedures and metrics are representative of field performance.

A recent examination of current international test procedures and metrics[1] identified recommendations to improve international alignment and better understand the issues and challenges surrounding new test methods for variable capacity ACs and HPs. The examination also noted the importance of international round robin testing as a means to better understand and align any differences in global AC and HP test methods for variable capacity equipment. Consistent, coordinated test procedures are important to provide clear market signals to consumers, provide meaningful drivers for product developers, and decrease test burden on manufacturers attempting to comply with many different regulatory schemes. This research follows those recommendations, with work to investigate and resolve issues with load-based testing of variable capacity ACs and HPs.

Research Overview and Goals

This research aims to develop an internationally applicable load-based test method for variable capacity ACs and HPs. The work has four phases:

1 | Investigate Innovative Test Methods
2 | Investigative Testing of Key Issues
3 | Development of Load-Based Test Methodology
4 | Round Robin Trial of Test Procedure

This report discusses the findings of Phase 2 (Investigative Testing of Key Issues), as well as the research team's recommendations for Phase 3 work. The key issues associated with load-based

[1] https://www.iea-4e.org/document/442/domestic-air-conditioner-test-standards-and-harmonization

have the potential to impact the test burden, repeatability, reproducibility, and representativeness of an international load-based test procedure.

The Phase 2 research goals were to:

1 | Conduct laboratory testing of three variable capacity HPs to investigate and resolve research questions

2 | Consult with international stakeholders to determine acceptable resolution of key issues and next steps in developing a load-based test procedure

Research Questions

Based on findings from the first phase of work, the research team sought to investigate key challenges related to load-based testing of variable capacity ACs and HPs. Table 1 summarizes the research questions relating to each key issue that the team sought to answer during the investigative testing.

Table 1: Research Questions Pertaining to Key Load-Based Testing Issues

Key Issue	Questions
Lab Setup / Instrumentation	
Lab System Control Dynamics	• Sensible Load: are adjustments to the control method for sensible load required? • Latent Load: are adjustments to the control method for latent load required? • Transient Considerations: what special considerations are needed to account for non-steady state conditions?
Input Component Bias/Offset	• Are any changes required to existing procedures for accounting for input component bias/offset? • Should more than one input component be considered?
Equipment Setup	
Influence of Thermostat	• How does thermostat placement impact results?
Test Unit Control Settings	• Should a uniform test method include settings such as Dehumidification, Eco Cool, and Eco Heat settings?
Adaptive Learning Algorithms	• How do adaptive learning algorithms affect testing?
Test Approach	
Load-based Test Concept	• Which load-based test approach produces the most repeatable and reproducible results?

Key Issue	Questions
Calorimetric / Air-Enthalpy	• Can both calorimetric and psychrometric methods of testing be included in a unified test?
Test Burden	• Does load-based testing increase manufacturer burden? If so, how much? • What techniques can mitigate increases to test burden?
Impact of Climate Region	
Climate Region	• Can climate-specific conditions be included in a unified test?

Section 2: Phase 2 Testing

Again, based on the feedback and issues identified in Phase 1, the research team conducted laboratory testing to further investigate the key issues in load-based testing of variable capacity ACs and HPs. The primary goals of this testing were to uncover differences between load-based test concepts, to understand the feasibility of implementing these different concepts, and perceive any potential increased test burden.

The research team developed a Phase 2 test plan with the following objectives:

1 | Apply load-based test concepts (dynamic and target load compensation) using various existing methods of test measurement (calorimetric & psychrometric)
2 | Evaluate test facility and test unit control responses in equilibrium and transient states[2]
3 | Investigate influence of control inputs, test unit control settings, equilibrium approach techniques, instrument response, and method of test measurement agreement
4 | Quantitatively evaluate the time required to perform various load-based test procedures

Phase 2 Overview

To meet Phase 2 objectives, the research team tested three split system heat pumps utilizing existing methods of measurement (i.e., 1 - Indoor Room Calorimeter, 2 - Indoor Air Enthalpy, 3 - Outdoor Air Enthalpy, and 4 - Refrigerant Enthalpy) in two separate test facilities to evaluate the feasibility of the different load-based concepts and to gain additional insights for test method correlation to be considered when developing the procedure in Phase 3.

The team initially planned to run 81 tests as part of this effort. The planned tests are included as Appendix 1. In all, 439 total tests were conducted over 11 weeks of testing. This significant increase was primarily due to the time required to learn and understand the control interaction between the test unit and the test facility, requiring many tests to be run multiple times in order to achieve valid results.

During test plan development, the research team considered four key factors, which are presented in more detail in subsequent sections:

1. **Load-based Test Concept**: Describes the type of load-based test. The research team considered dynamic load response versus target compensation load test concepts, and whether to implement those in a full ratings test or as a way to verify controls performance outside of steady-state compressor efficiency testing.
2. **Method of Test Measurement**: Describes how equipment performance is measured in the lab. The team considered psychrometric and calorimetric approaches.

[2] The transient state of defrost was specifically excluded from the scope of this research and test procedure development in order to first focus on developing a non-transient test procedure.

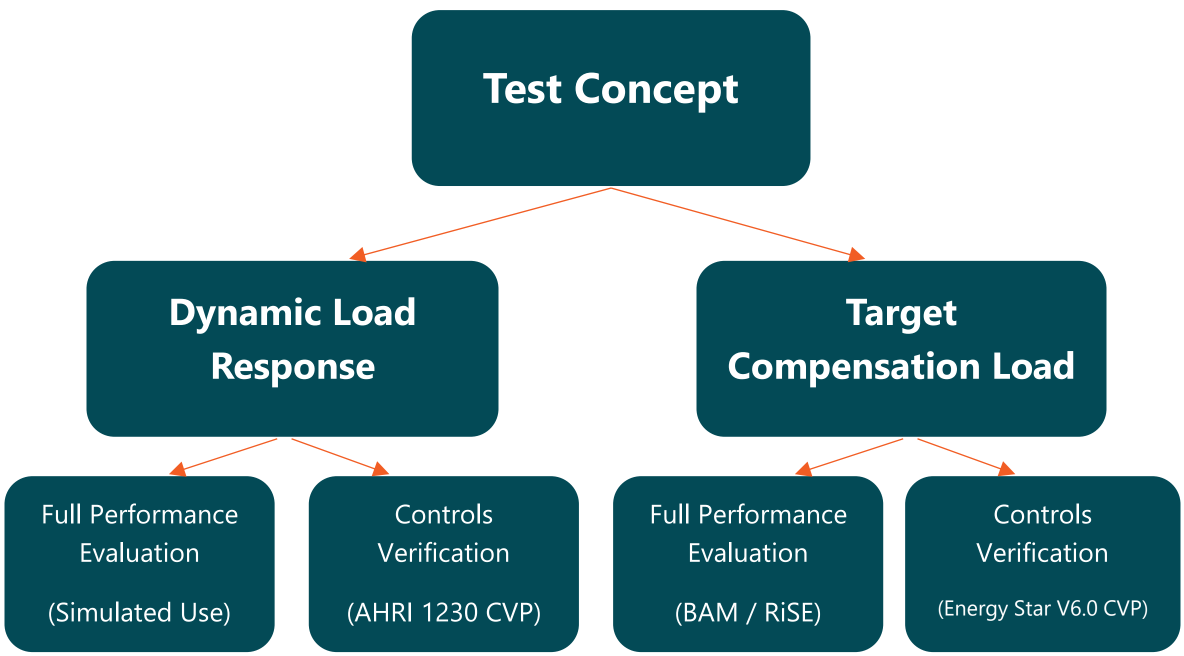
3. **Units Under Test (UUT)**: Describes the type, number, and capacity of the equipment selected for testing.
4. **Testing Sequence**: Describes the specific tests each unit was subject to.

The following sections describe the details of the investigative testing in accordance with those four factors.

Load-based Test Concept

During its review of innovative test methods, the team found that the existing load-based tests use two distinct testing concepts: dynamic load response or a target compensation load. Dynamic load response testing uses a continuously variable (increasing or decreasing) load imposed on the UUT to allow the native controls to respond. A target compensation load utilizes a stable load imposed on the UUT in an unlocked compressor state. This allows the system controls to react and ultimately achieve a balanced steady-state condition. Figure 1 shows a high-level breakdown of which innovative load-based test procedures incorporate each of these test concepts.

Figure 1: Load-Based Test Concepts



Ideally, either of these fundamental testing concepts could be implemented directly to determine equipment COPs and ratings in lieu of traditional steady-state testing. However, the existing measurement methods typically strive for test chamber and test unit equilibrium in order to accurately measure capacity and efficiency. Since the very nature of a dynamic load response test does not allow for steady-state equilibrium to be achieved, the Phase 2 test plan *primarily* investigated the target compensation load test concept using the test unit native controls.

The team conducted limited testing of a dynamic load response in two different manners. The first is a full cycle of simulated use where the indoor load varied as a function of outdoor ambient temperature. Both capacity and power are then integrated over the entire cycle to determine system performance. The second is maintaining the outdoor ambient and steadily decreasing the indoor load to approach the capacity target. This second manner is similar to the AHRI-1230 controls verification procedure (CVP)[3].

Method of Test Measurement

As determined in Phase 1, measuring AC and HP capacity is traditionally done using one of the following two methods of test measurement:

- Calorimetric (capacity based on balancing the space conditioning produced by the UUT against the measured heating/cooling and water energy inputs)
- Psychrometric (capacity based on enthalpy measured at the inlet and outlet of the equipment and mass flow of the air/refrigerant)

Phase 1 polling of stakeholders found overwhelming support to include both test measurement approaches to better align with global measurement approaches. Therefore, in Phase 2 testing, non-ducted test units were tested using both methods of test measurement while the ducted unit was tested using only the psychrometric test measurement approach. The following sections explain the reasoning for this and describe the measurement approaches for each in more detail.

Non-ducted Systems

Across Europe and Asia, non-ducted units are typically tested in a calorimetric chamber. However, they are more commonly tested in psychrometric chambers in North America. When testing non-ducted systems in a psychrometric chamber where ductwork is connected, precautions are required to avoid issues such as influencing the air properties (by interfering with the supply and return air paths) or influencing the air volume rate/fan power (due to interactions with the airflow measurement apparatus).

The majority of investigative testing of non-ducted systems in Phase 2 utilized a hybrid of both calorimetric and psychrometric measurements. The hybrid test facility was a modified psychrometric room that included a calibrated box on the indoor side and an outdoor air measurement apparatus to allow for an energy balance confirmation at full load in both cooling and heating modes. The hybrid "box" was fully calibrated per ASHRAE Standard 16 prior to conducting investigative testing. This non-ducted lab setup is shown in Figure 2. This hybrid

[3] https://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_1230-2021.pdf

method was used in order to replicate a room calorimetry approach and eliminate the potential issues that occur when attaching ductwork and airflow measurement apparatus.

Limited validation tests using psychrometric methods were also conducted at specific load points.

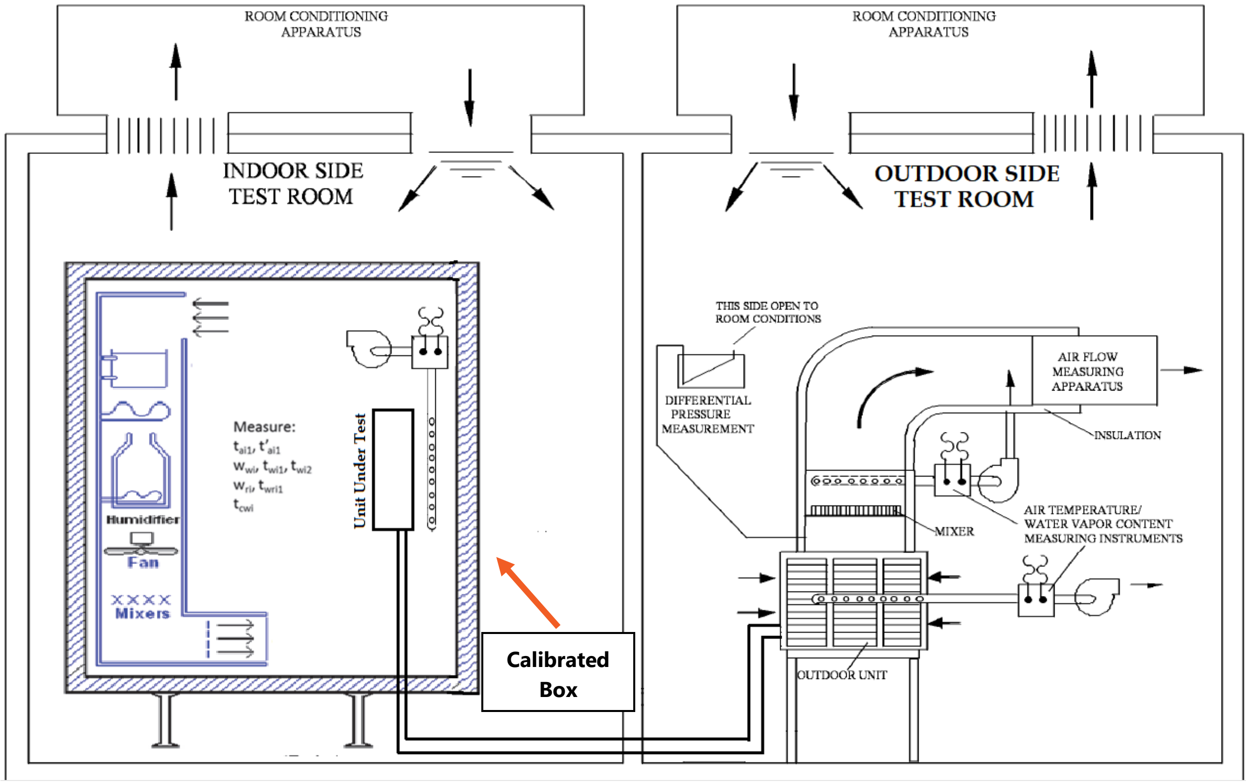


Figure 2. Non-ducted Lab Setup showing Indoor Calibrated Box within Psychrometric Room

Ducted System

The ducted system was evaluated in a standard psychrometric facility with modified parameters to allow for manual control of sensible and latent loads. This manual load control differs from current steady-state test procedures (such as ISO 5151) but is necessary to achieve the changing loads needed for load-based testing. Indoor air enthalpy was used as a primary method for capacity determination. The refrigerant enthalpy method was used as a secondary capacity determination when the metering device was located in the indoor section[4]. Alternatively, the outdoor air enthalpy method was used to confirm energy balance at full load cooling and heating operation.

[4] Some non-ducted units have the EEV in the indoor unit, while some place them on the outside unit.

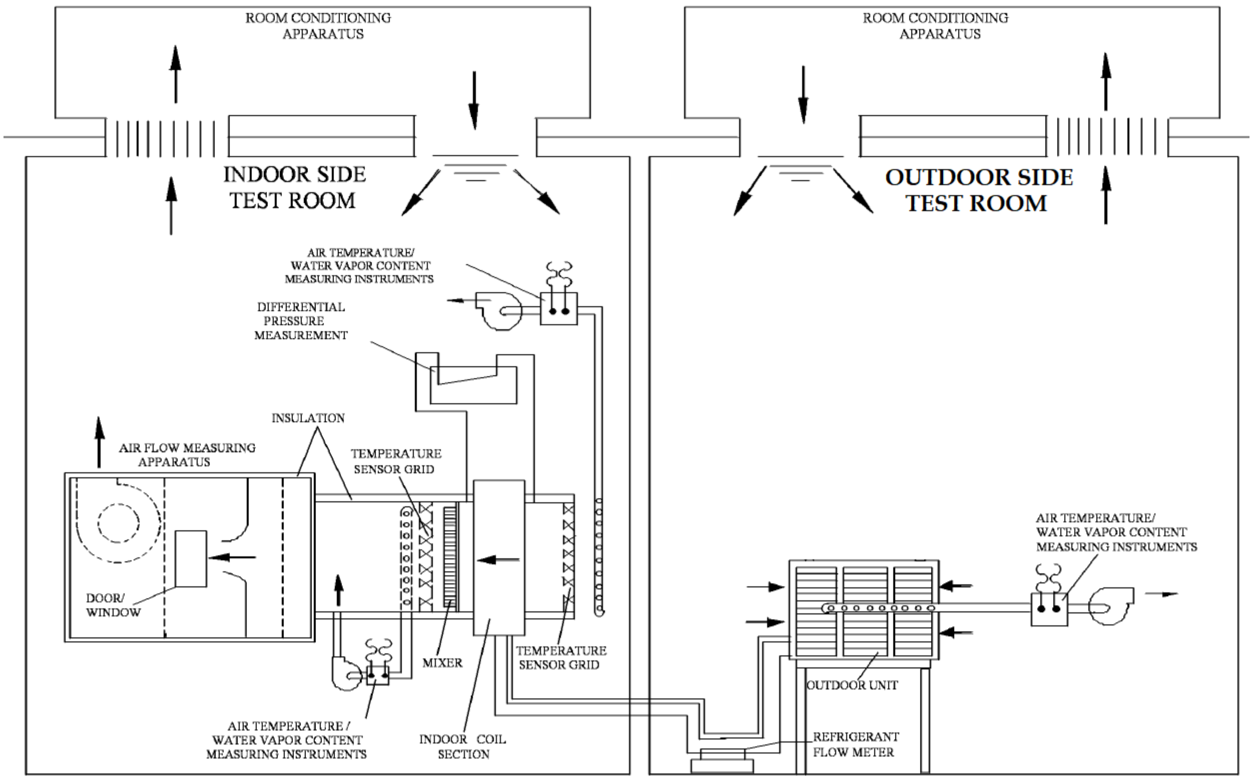


Figure 3. Ducted Unit Lab Setup showing Psychrometric Rooms[5]

Units Under Test

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. Heat pumps were selected for testing instead of AC units to allow for both heating and cooling modes of operation.[6] Units under test (UUT) were selected to cover a range of capacities, but also to allow for testing using the calorimetric room method, which is typically limited to 36,000 Btu/h capacity. UUTs were also selected from three different manufacturers to represent different manufacturer control schemes. The units selected are summarized in

Table 2.

[5] Source: ASHRAE 37-2009 (Figure 1)

[6] The original scope of work emphasized research into the cooling function of AC/HP equipment only. The scope was expanded to include heating mode (but excluding transient operation such as defrost and oil return) during Phase 1.

Table 2: Units Under Test

Test Unit	Nominal Capacity	Configuration/ Indoor Arrangement	Measurement Methods
1	15,000 Btu/h / 4.5 kW	• Non-ducted ASHP • Single split • Wall mount blower coil	• Indoor room calorimeter- primary • Outdoor air enthalpy- secondary • Indoor air enthalpy- limited validation
2	24,000 Btu/h / 7.0 kW	• Non-ducted ASHP • Single split • Wall mount blower coil	• Indoor room calorimeter- primary • Outdoor air enthalpy- secondary • Indoor air enthalpy- limited validation
3	36,000 Btu/h / 10.5 kW	• Ducted ASHP • Single split • Ducted blower coil	• Indoor air enthalpy- primary • Refrigerant enthalpy- primary

Each UUT underwent a series of tests using various *test concepts* and *measurement methods*. Measurement methods include indoor room calorimeter, indoor air enthalpy, outdoor air enthalpy, and refrigerant enthalpy, as indicated in the table above. While lab technicians utilized the indoor room calorimetry and indoor air enthalpy measurement methods for primary capacity measurement, alternate measurement methods were used obtain a secondary capacity measurement for the full load heating and cooling capacity of each tested system to validate the results.

Test Sequences

Non-ducted and ducted systems had separate test sequences. The research team developed these sequences to investigate the unanswered questions from Phase 1. The general approach for both ducted and non-ducted equipment was to calibrate and characterize the test facility and measurement apparatus, which now includes the native equipment controls, and then conduct a series of different performance tests via different load-based approaches and/or at different control settings. The team then considered the findings from this suite of investigative tests to inform the answers to the key issues identified in Phase 1. Figure 4 gives an overview of the non-ducted test sequence. The indoor calorimeter box was first calibrated to evaluate the thermal loss and moisture intrusion. Then balance tests were conducted to ensured accuracy over a range of conditions. Finally, technicians completed the performance tests.

Figure 5 shows an overview of the ducted test sequence. For the ducted unit, validation tests included examining different thermostat offsets, evaluating the equipment control dead band, and refrigerant charge adjustments to achieve the manufacturer specified sub-cooling targets. Since the ducted unit's metering device was located in the indoor unit, the secondary capacity measurement using a refrigerant enthalpy measurement apparatus was utilized for all tests and separate energy balance confirmation tests using an outdoor air enthalpy measurement apparatus were not required.

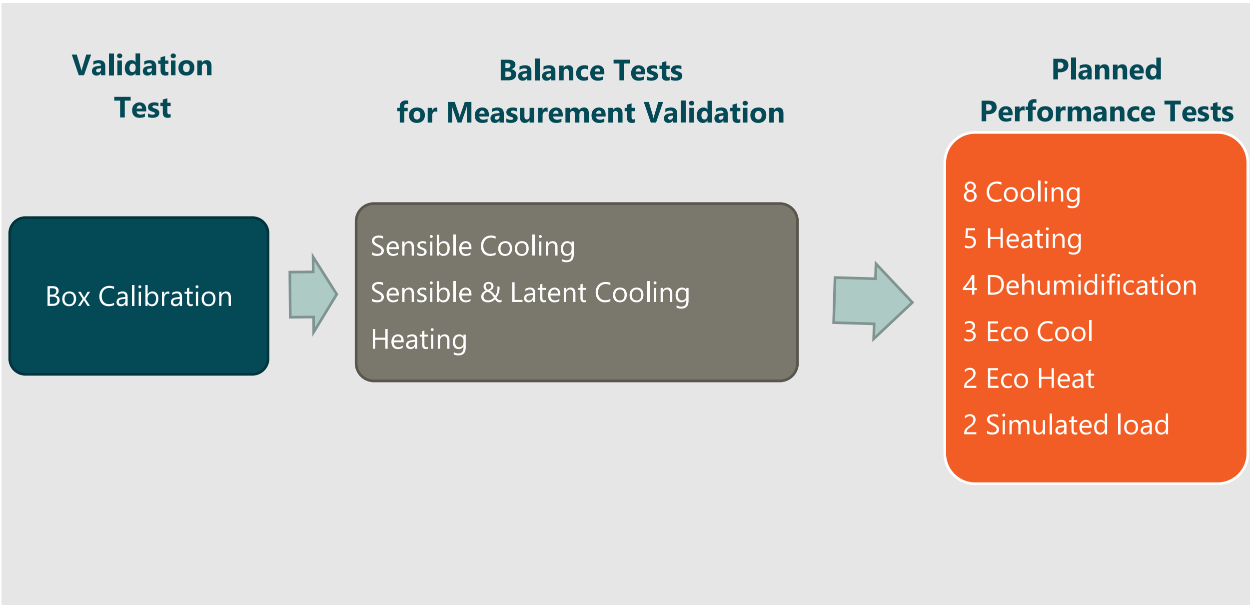


Figure 4. Non-ducted unit test sequence

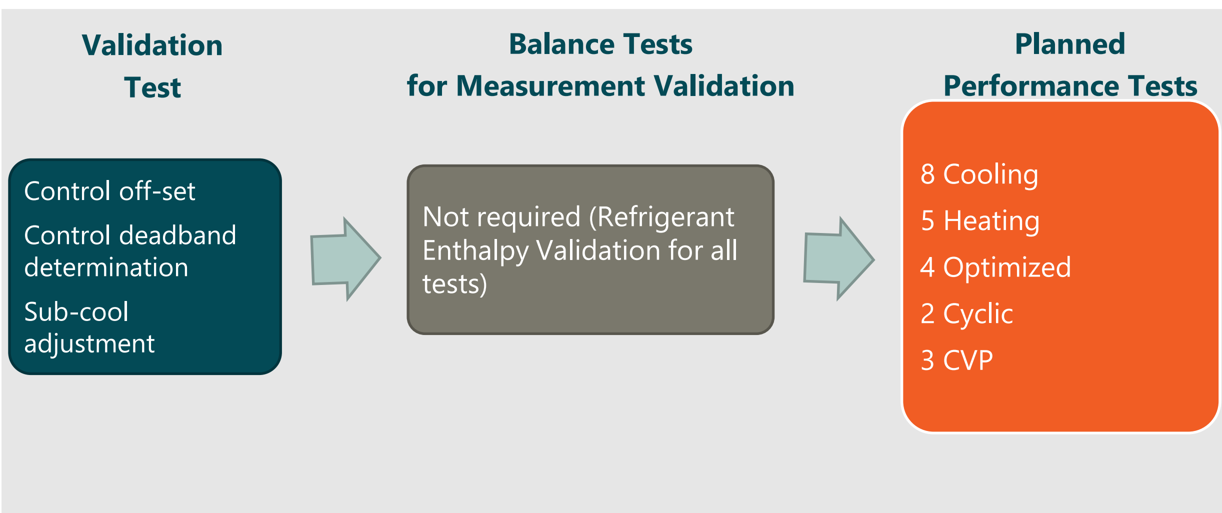


Figure 5. Ducted unit test sequence

Appendix 1 shows a detailed investigative test matrix, outlining all tests performed. Section 3 is a summary of findings and recommendations from the investigative testing.

Section 3: Findings & Recommendations

This section details the high-level findings from Phase 2, along with recommendations as the project moves into Phase 3. Detailed findings to support these recommendations are in Appendix 2.

The key findings, which are discussed in more detail below, are:

- Dynamic load testing, since it does not achieve equilibrium during testing, does not produce consistent enough results for a ratings test.
- Target compensation testing can produce repeatable and reproducible results.
- Non-ducted units should be tested in a separate manner due to several peculiarities compared to ducted units.
- Testing using a variety of control settings adds complexities and burden that may not be beneficial to all climate regions.
- Lab setup is critical to make sure results are repeatable and reproducible. Synchronization of UUT and lab fans, lab sensor locations, sensor requirements, and calibration are all essential.
- The proposed test procedure developed in Phase 3 should lay out all necessary data collection details, but the test points and rating calculations should be decided by the authority having jurisdiction (AHJ).

The following elaborates on these findings and recommendations.

Load-Based Test Concept

As discussed previously, in Phase 1 the research team presented two possible approaches to incorporating native controls into existing test methods for variable capacity AC/HP: dynamic load testing and target compensation loading. Either method could be used to determine COP and ratings in lieu of traditional steady-state testing. Alternatively, either approach could be implemented through a CVP. In this style of CVP, the data from the limited load-based testing are instead *compared to* the steady-state data to validate or confirm the representativeness of those more accurate and precise values.

Dynamic Load Description

In the Phase 1 outreach forum discussions, stakeholders agreed that while a dynamic load response test is appropriate to observe and validate controls behavior, it is less favorable to measure performance results due to the difficulty of providing repeatable and reproducible results. Current measurement methods (i.e., room calorimeter, air enthalpy and refrigerant enthalpy) require the test chamber and UUT to achieve equilibrium to accurately measure capacity and efficiency. This can be challenging because a dynamic load response test would invariably prohibit equilibrium. The continuously variable load injection, and the lag in response from equipment controls as compared to test chamber controls, can often result in the equipment and test chamber controls "fighting" each other and causing erratic and non-representative behavior. However, stakeholders agreed that Phase 2 testing should evaluate factors which impact both the test chamber and the UUT from achieving equilibrium. Stakeholders also suggested that dynamic test burden impacts could be mitigated by more detailed procedures than current load-based test procedures provide.

Phase 2 testing included limited investigation of dynamic load response test concepts by utilizing two different methodologies. The first method was a simulated use test: a representative cycle of steadily increasing, then decreasing indoor loads that correspond to a range of outdoor ambient conditions. Both power and capacity are then integrated over the entire cycle. The second method was a CVP that maintained the outdoor ambient condition and steadily decreased the indoor load to approach either the capacity target or minimum capacity turn down before compressor on/off cycling. This method is similar to the AHRI 1230 CVP.

Target Compensation Load Description

During Phase 1 outreach forum feedback, a majority of respondents expressed a preference for target compensation load testing. The target compensation load test would lead to a better balance of repeatable and reproducible results as the intent would be for the test chamber and the test unit to attain equilibrium. The target compensation load would also allow for direct application of the existing measurement methods.

Findings- Dynamic Load Response

Lab technicians performed simulated use tests on the non-ducted units in the calibrated box. These tests, using steadily increasing and decreasing indoor loads corresponding to an increase and decrease in outdoor ambient temperatures, resulted in large temperature swings measured at the return air sensor. This response of UUT 2 is shown in Figure 6. The red line shows the erratic return air temperature. The blue line shows dramatic cycling of the unit power consumption. The transients of the test room power, moisture injection, and room thermal uniformity had a lead/lag relationship with each other as well as with the unit response. This interaction was dependent on the size, thermal mass, controllability of the moisture injection, and airflow distribution patterns in the calibrated box. As the calorimetric approach requires equilibrium to trust the calculations, this behavior showed that the calorimetric approach is not suitable for dynamic simulated use testing with a high degree of certainty. The research team was not able to estimate the burden of simulated use testing, and at the time of writing, no published data is available to confirm any additional burden.

PHASE 2 DYNAMIC TESTING

Included both simulated use testing and AHRI 1230-style CVP

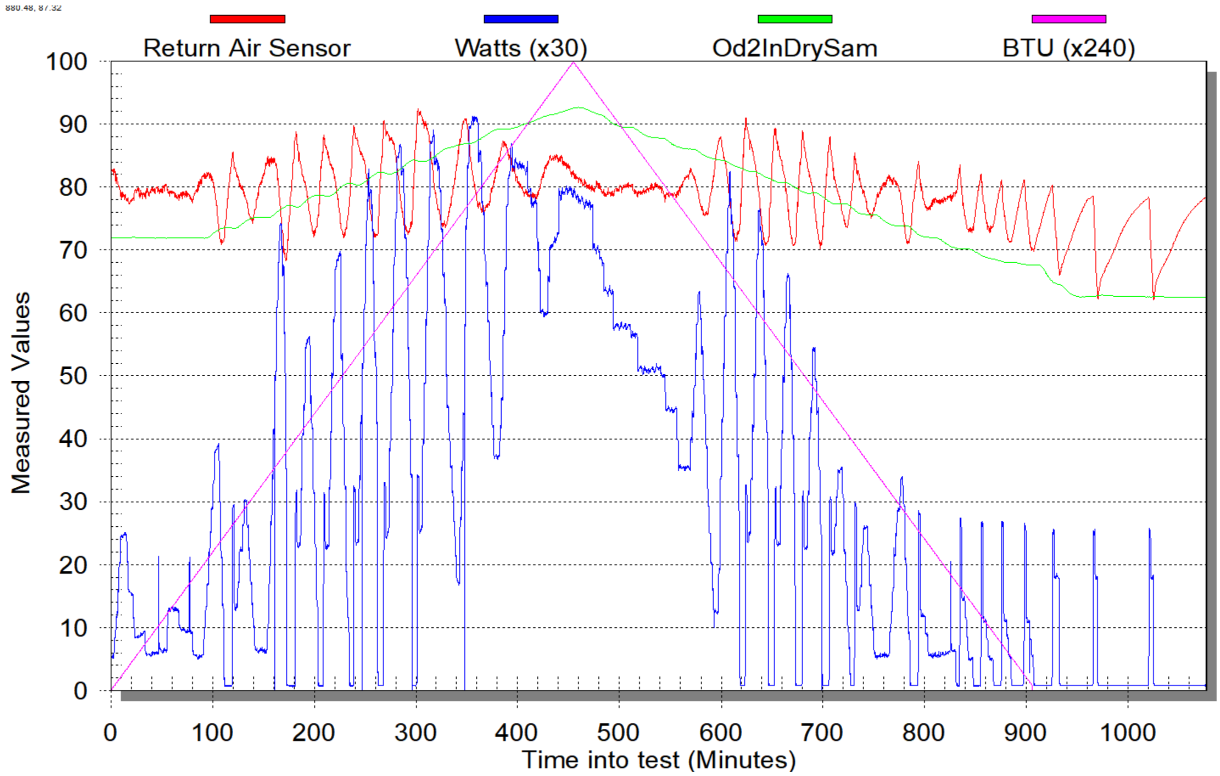


Figure 6. UUT 2 Results of Simulated Use Test

In addition to the simulated use dynamic load response testing, lab technicians performed an AHRI 1230 CVP-style dynamic load response test on both ducted and non-ducted units. As described above, the AHRI 1230 CVP-style dynamic load response test maintains the outdoor ambient temperature and steadily decreases the indoor load to approach the capacity target or minimum compressor speed before on/off compressor cycling occurs.[7] The non-ducted units showed limited success validating performance, and also highlighted a previously unknown complication that multiple adjustments for thermostat offset were required to achieve the target indoor conditions. Figure 7 shows this complication for the non-ducted UUT 1. The green line shows how the UUT would shift offset at various loads. Technicians made adjustments to the thermostat (T-Stat Adjustment 1, 2, and 3) to account for the offset.

The paragraph above describes the difficulty with calorimetric testing in non-steady state and this section was intended to show the sliding offset further complicated a 1230 style CVP with

[7] Contrary to the AHRI 1230 CVP, there are no certified critical parameters (e.g. compressor speed, condenser fan speed, expansion device position) for modulating components. Therefore, a root sum square critical parameter point total could not be used as the validation criteria. Instead, the capacity and power for a 5-minute period bracketing the target capacity (or 5-minute period preceding the compressor off for the lowest temperature minimum load test points) were used to compare against the steady-state test points.

continuously decreasing load because the offsets would inherently create another transient effect that would impact the unloading process.

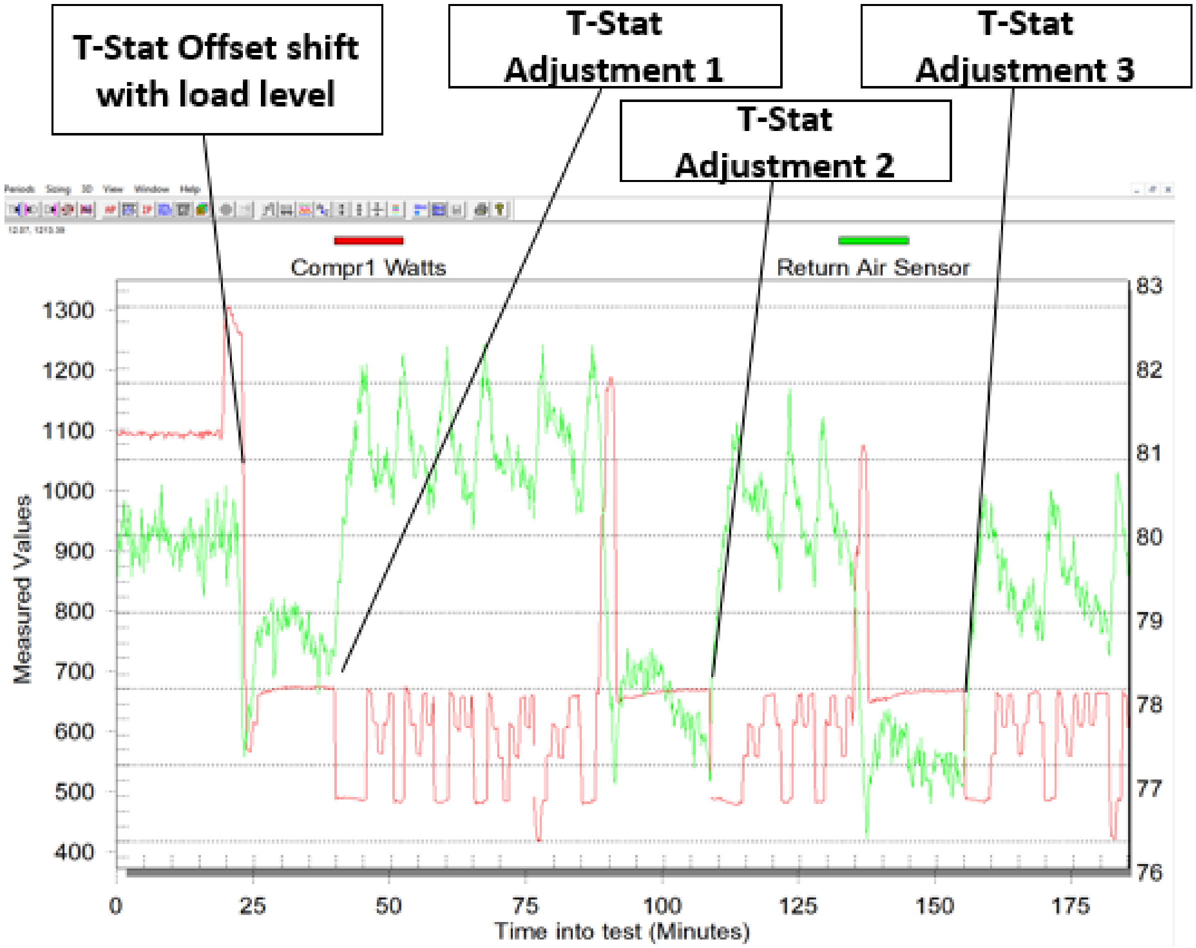


Figure 7. Thermostat Offset Shifts during AHRI 1230-style CVP (Dynamic Load) Non-ducted UUT 1

For the ducted unit, UUT 3, the dynamic CVP test validated that the capacity, power and instantaneous EER at multiple loads were within reasonable limits. These results are shown in Table 3. While 6% variation at minimum load exceeds typically accepted regulatory tolerances for testing and evaluating seasonal unit performance, the research team believes this is an acceptable level of tolerance for validating controls performance at individual regulatory test conditions.

Table 3. Comparison of Dynamic CVP Results to Steady-State Results for UUT 3 (ducted)

Test Conditions	Test Type	Capacity	Power (W)	EER	% Difference from CVP
Med Temp Min Load	CVP	13,378 Btu/h 3.92 kW	525	25.67	
Same as above	Steady-State	14,004 Btu/h 4.10 kW	552	25.99	0.54%
Low Temp Min Load	CVP	17,645 Btu/h 5.17 kW	457	38.61	
Same as above	Steady-State	14,672 Btu/h 4.21 kW	358	40.99	6.16%

Phase 2 lab logs showed that this type of CVP required an additional 3-4 hours per CVP, or an additional 25-40% test burden over steady-state testing.[8]

Findings- Target Compensation Testing

The target compensation load testing was performed on all three UUTs and showed varied levels of success. The UUT responses are shown in Figure 8. UUT 3 (ducted) performed as anticipated. UUT 2 (non-ducted) also performed as anticipated with the exception of periodic oil returns. UUT 1 did not respond to the fixed compensation load as anticipated and showed aggressive temperature controls (specifically, a temperature control dead band of less than 1°F / 0.5°C). This required modifications to the target compensation load method. Technicians allowed the load to vary slightly (3% for UUT 1- other units did not require a load variance).[9] In this limited sample size, after the modifications, all UUTs were able to produce consistent, repeatable results.

Phase 2 lab logs showed that compensation load testing required an increased test time by 60-250% over steady-state testing. UUT 2 and UUT 3 were on the low side of this increase and the majority of this increase can be attributed to calibrating the set point offset(s) at each load. UUT 1 resulted in the high end of this increase as a result of calibrating the set point offsets at each load as well as the aggressive control deadband.

Table 4 shows an overview of the strengths, weaknesses, and burden for the various load-based test schemes.

[8] All burden references are in comparison to the US DOE Appendix M1 test procedure that is scheduled to take effect in 2023.

[9] See Figures 13 through 16 in Appendix 2.

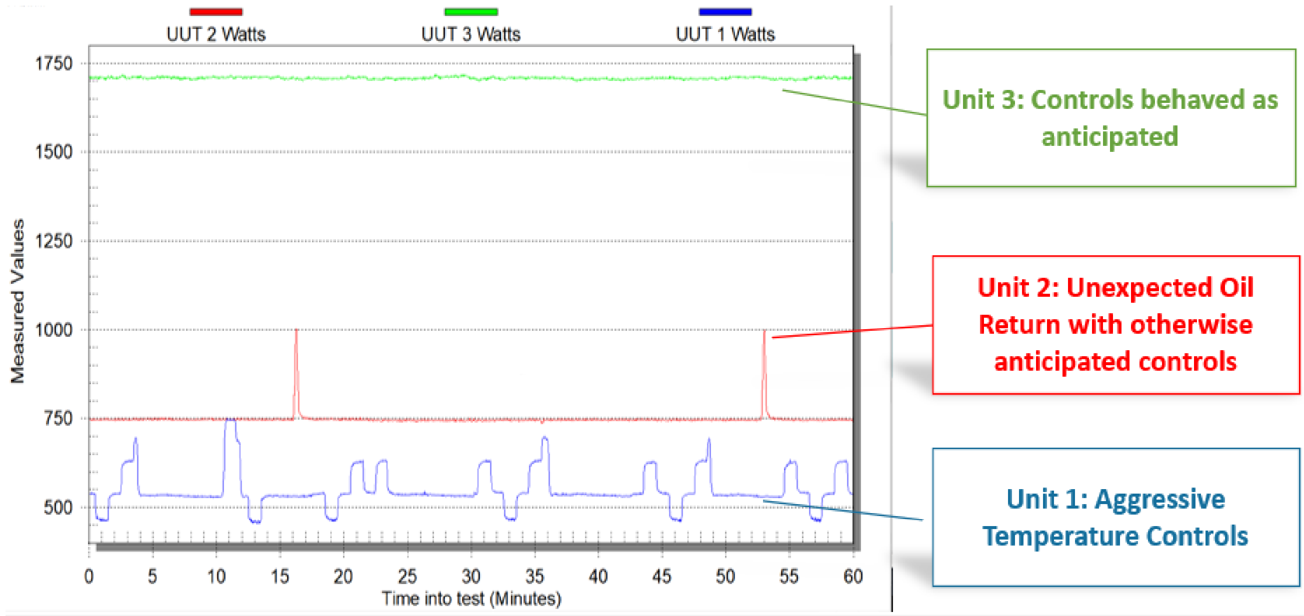


Figure 8. Cooling Target Compensation Load (Fixed 2/3 Compensation Load at Mild Outdoor Conditions)

Table 4. Comparison of Different Load-based Test Methods

Test Concept	Strengths	Weaknesses	Additional Burden (Test Time)
Dynamic Load Response (Simulated Use)	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
Dynamic Load Response (AHRI 1230 CVP-style)	Tests the native control response to dynamically changing loads	Not suitable for direct measurement of performance	25% to 40% increase
Target Compensation Load	Provides some benefit of native control since tests do not lock compressor speeds. Better repeatability/ reproducibility than simulated use testing	More controlled nature of test conditions may demonstrate less real-world controls response	60% to 250% increase

Recommendation

RECOMMENDATION:

TARGET COMPENSATION CVP

- Confirmation of steady-state results
- Uses native controls
- Better R&R than simulated use

The team recommends utilizing a target load compensation test as a controls verification procedure to validate system performance and operation at any test/load condition specified by the AHJ where the compressor speed or other modulating components are manually overridden for the ratings test.

This type of CVP test balances the outreach forum feedback to: incorporate system controls, maintain repeatability and reproducibility tolerances, minimize increase of test burden, and minimize adjustments to current lab setup. It allows for testing of equipment under native controls. Since it does not rely on such testing for the specific determination of equipment capacity and performance values, there are less concerns about repeatability and uncertainty. In this style of CVP, the data from the limited load-based testing are instead *compared to* the steady-state data to validate or confirm the representativeness of those more accurate and precise values. If the results from the CVP test suggest that equipment controls affect the performance of the unit such that the steady-state testing is not representative, an AHJ could require that the steady-state testing be re-run with compressor speed and operating characteristics dictated by the CVP.

Specific recommendations for this CVP test method are:

- The test unit should be operated under native controls,[10] incorporating the appropriate thermostat or remote controller
- The installation location, temperature uniformity and air velocity at the thermostat or remote controller should be measured and representative of a typical installation[11]
- Adjustment for thermostat set point offsets at each load point should be required[12]
- The compensation loads are initially set at the target capacity determined by the regulatory tests. The compensation loads are allowed to vary, slightly, to achieve equilibrium with the test unit[13]

[10] As determined from the manufacturer's installation instructions.
[11] The test method will include requirements for control device and instrumentation requirements to ensure representative test temperatures and air velocities, as well as test room requirements to minimize impacts from turbulent air current. The AHJ should determine temperature conditions and duct static pressures for their respective region.
[12] The thermostat offset is determined by the lab during testing using an established procedure. More information on this process can be found in the "Equipment Setup" section of this report.
[13] This will prevent the generation of non-representative or erroneous results due to interaction of the equipment and test chamber controls, as the research team observed on UUT 1.

- If the system is unable to operate at the target load without compressor on/off cycling, the compensation load should be increased incrementally until there is no on/off compressor cycling

Requirements set at the jurisdictional level include:

- AHJs should determine and specify temperature conditions and duct static pressures that are representative of typical installations for their respective regions.
- AHJs should set limitations for how closely one must meet the target loads
- AHJs can require that manufacturers re-run steady state tests with capacity and power values determined from the CVP

Non-ducted Unit Testing

As explained in the Phase 2 Overview, the team tested non-ducted units separately in this phase of research. Lab technicians constructed an indoor room calorimeter creating a room from insulated panels inside an existing psychrometric chamber and calibrated its thermal properties.

Findings

Non-ducted units showed spot-cooling behavior much like residential room air conditioners. Figure 9 shows how UUT 2 would control the supply air temperature at the "end of throw" to match the unit set point. With the thermostat set at 76°F (24.4°C), the return air temperature varied, but the temperature measured at the end of the supply airstream was essentially stable. When lab technicians changed the set point to 75°F (23.9°C), end of throw adjusted and stabilized at 75°F.

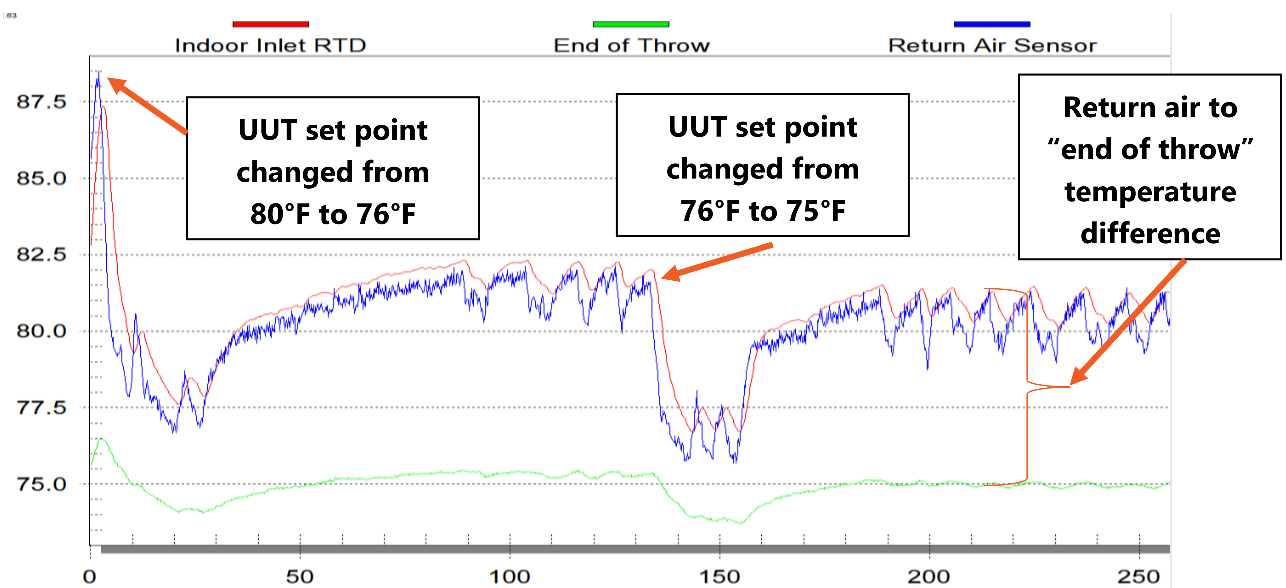


Figure 9. Non-ducted UUT 2 Spot-Cooling Behavior

Previous testing has shown that adding ductwork to non-ducted units can be problematic. If the test lab does not manage external static pressure properly, the UUT fan can "flip" and run in the opposite direction, throwing off the measurements. The calibrated box calorimeter allowed the UUT to be tested without the influence of ductwork.

RECOMMENDATION:

TEST NON-DUCTED UNITS CALORIMETRICALLY

- Non-ducted units behave differently
- Prevent "flipping" of fan
- Use calorimeter or calibrated box in psychrometric chamber

Recommendation

The team recommends development of a separate test procedure specifically for non-ducted units because of behavioral differences and issues with static pressure. Non-ducted units should be tested either in a calorimeter or in a calibrated box inside a psychrometric room.

Primary measurements should be made using calorimetric methods on the calibrated box. Secondary measurements should be made using psychrometric methods on the outdoor air.

Equipment Setup

Two components of the equipment setup can have a large impact on test results: thermostat offset and settings of the controller. This section explores both of these facets.

Offset

The primary control input for residential ACs and HPs is the return temperature (or difference between the return air temperature and control set point) in nearly all known test units. Laboratory findings have shown that some manufacturers introduce an offset or bias in the return air temperature control. This offset will control the conditioned space to a different setting than shown on the controller. For example, a HP in heating mode may control to a 69°F (20.6°C) return air temperature, even if the thermostat is set to 70°F (21.1°C). In accordance with recent research recommendations, innovative test methods account for any offset and bias in the return air thermistor by calibrating to the laboratory return air sensors prior to testing.[14]

In addition to controlling via return air, some ACs and HPs—specifically variable capacity units—use multiple control loops that operate simultaneously. Rather than relying solely on return air temperature, this allows the unit to control for safety, durability, and unit performance. Current test approaches do not control for offset and bias in these additional sensors.

[14] Cheng, Li; Patil, Akash; Dhillon, Parveen; Braun, James E.; and Horton, W. Travis, "Impact of Virtual Building Model and Thermostat Installation on Performance and Dynamics of Variable-Speed Equipment during Load-based Tests" (2018). *International Refrigeration and Air Conditioning Conference.* Paper 2078. https://docs.lib.purdue.edu/iracc/2078

The team pursued understanding of other input offsets, but without being able to see the control programming or monitor the control system input values, it was difficult to determine additional causes of unstable operation and attribute them to specific sensor input or feedback.

Settings

The test unit control settings define how the UUT is set up and programmed to operate during testing. A literature review showed various combinations of *operating modes, function modes and special features* were available to customize based on installation location and consumer preference. *Operating modes* include Auto, Cool, Heat, Fan Only. *Function modes* include Dehumidification, Economy/Energy Save, Jet/Turbo, Dry Cooling, louver operation, defrost configuration and a variety of fan speed or speed tap settings. *Special features* include various modes such as occupancy sensing, low noise, away freeze protection, air purification, anti-mosquito and ion generating. Some of these types of special features are shown in Figure 10.

(2) Display Screen	Description
	To purify the air by removing particles that enters the indoor unit.
	To reduce noise from outdoor units.
	To keep your skin moisturized by generating ion clusters.
Po	To lower indoor humidity quickly.
LH	To maintain a minimum room temperature and prevent objects in the room from freezing.
	To scare away a mosquito.

Figure 10. Examples of Unique Special Feature Settings

Ducted and non-ducted control setting options are often quite different. Non-ducted units typically offer a wider variety of possibly settings. Ducted units typically offer fewer options.

Phase 2 investigated how units behave according to different control settings and using different control inputs.

Findings- Offset

Return Air (RA) temperature control offset is not consistent from test to test for two of the three units. Figure 11 shows the different offsets observed during testing. Both non-ducted units changed offset at different fan speeds. UUT 1 (light green lines) had the most dramatic variance in offset. At high fan speeds, UUT 1 had an offset of 7°F (4°C) in cooling mode and 5°F (3°C) in heating. This dropped down to only 1°F (0.6°C) offset at low fan speed, for both heating and cooling. UUT 2 (dark green lines) had offsets varying from 4°F (2°C) down to 1°F. The ducted unit, UUT 3 (blue lines), had constant offset at all fan speeds: 6°F (3°C) for heating and 3°F (2°C) for cooling.

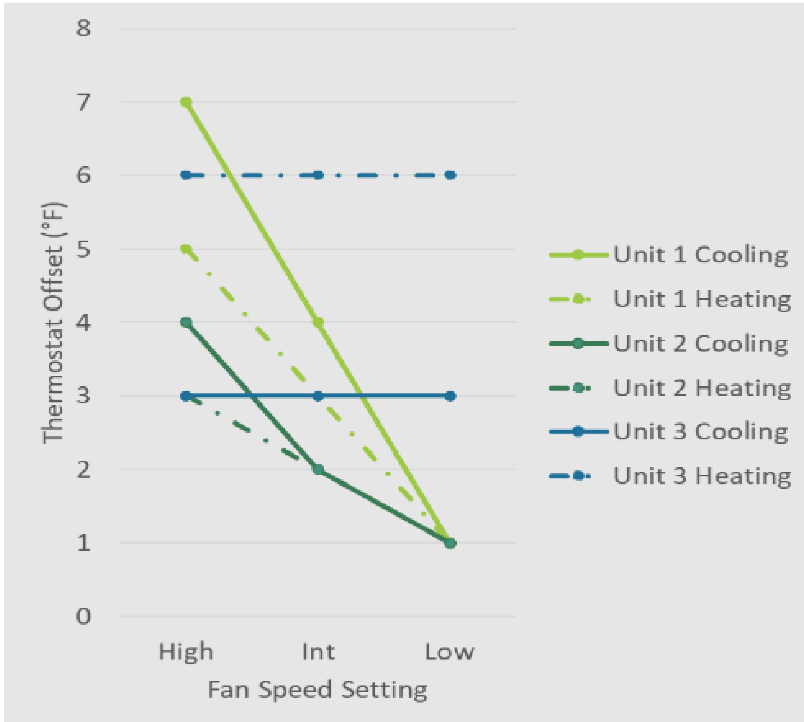


Figure 11. Return Air Offset Values at Different Fan Speeds

These findings show that offsets need to be determined through testing and incorporated into load-based tests.

Findings- Settings

The influence of settings also varied from unit to unit. Both non-ducted units had a multitude of setting options, ranging from standard heat/cool/auto to settings that claim to moisturize skin and scare mosquitos. The lab technicians compared the performance of three settings that consumers might commonly choose: cooling, dehumidification, and “eco.” UUT 1 showed performance differences with these settings, but UUT 2 had virtually no change in operation or efficiency.

UUT1 incorporated an occupancy sensor that was factory default set to “On” and required modifications to operate in the test facility for extended periods. Table 5 shows a comparison of the performance between base cooling, dehumidification and energy save modes. “Eco” mode resulted in a reduction in maximum compressor speed. However, the target compensation load tests showed no measurable impacts due to the fact that the rated, intermediate and minimum capacity tests were all at or below the reduced maximum compressor speed.

Table 5. Comparison of UUT 1 Performance with Different Settings

Unit Setting	Capacity (Btu/h)	Capacity (kW)	Power (W)	EER	T-Stat Offset (°F)
Cooling	15,728	4.61	1096	14.35	7
Dehumidify	15,133	4.44	1150	13.16	7
Eco	15,658	4.59	1090	14.36	7

The only measurable impact for UUT 2 was on the thermostat offset. Table 6 shows a comparison of the performance from different operating modes. The capacity, power, and EER for each setting are essentially the same, but the offset varied from 4°F to 8°F (2°C to 4°C), depending on the mode.

Table 6. Comparison of UUT 2 Performance with Different Settings

Unit Setting	Capacity (Btu/h)	Capacity (kW)	Power (W)	EER	T-Stat Offset (°F)
Cooling	18,129	5.31	1374	13.19	4
Dehumidify	17,467	5.12	1340	13.03	6
Eco	17,738	5.20	1344	13.19	8

The ducted unit, UUT 3, did not have these same options and was not tested in this way.

Recommendations

More test modes will necessitate more time spent determining offset/bias, which increases burden. Given the wide variety of possible settings and different nomenclature and functionality employed by different manufacturers, testing a wide variety of control strategies would be difficult to clearly specify, could negatively impact repeatability, and may introduce uncertainty in the market, as not all controls will be applicable to different climates. As such, the team recommends that settings other than heat and cool should not be a focus of a unified test procedure.

RECOMMENDATION:

LIMITED CONTROL MODES FOR TESTING

- Reduces burden
- More straightforward

The research team recommends limiting control modes for required testing, but allowing optional tests as determined by the AHJ based on local climate conditions.

When performing the CVP for any specified control (heat, cool, or another mode specified by an AHJ), the team recommends the following hierarchy be incorporated into the test method to determine which control settings to use:

1. Recommended control settings determined from manufacturer installation manual
2. Next, refer to the product label instructions
3. Next, use the manufacturer default settings (as-shipped, or configured per installation manual)
4. Finally, use the basic heating or cooling setting with auto fan, if none of the above are available

This will provide lab technicians with a logical sequence to follow to ensure better reproducibility.

Lab Setup

Current test procedures in different regions have different requirements for arranging the lab and testing equipment. For this testing, the team set up the psychrometric room according to ASHRAE 37 and the calibrated box according to ASHRAE 16. These testing instructions are more specific than most ISO standard procedures.

Findings

The typical lab set up does not require synchronizing the UUT and lab fans. This resulted in different energy calculations and introduced uncertainties. Figure 12 shows the difference in instantaneous capacity as calculated with the refrigerant enthalpy method (red data) and air enthalpy method (green data). Inconsistent UUT fan step control and missed “fan off” timing resulted in significant energy balance shifts. Calculations using the refrigerant enthalpy method consistently performed between 4% and 11% higher than air enthalpy method.

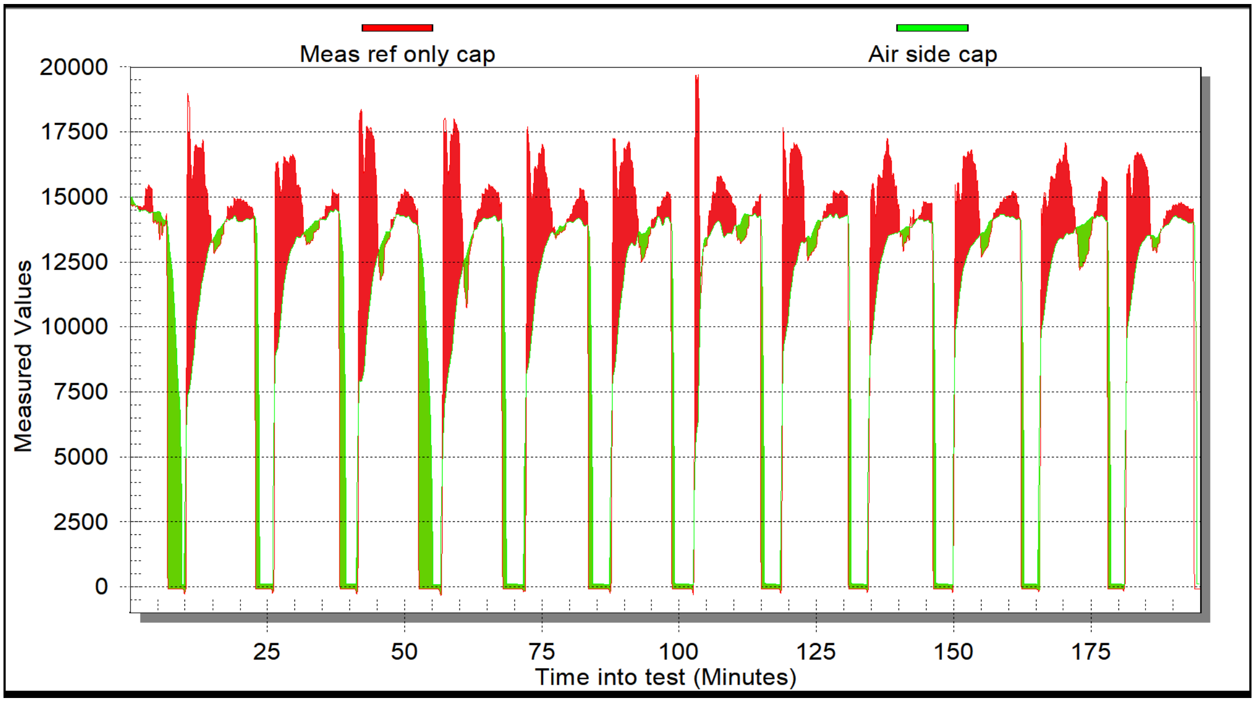


Figure 12. UUT 3 Capacity Measurement Comparison

Recommendations

To ensure repeatability and reproducibility, the team will develop a test procedure that is specific about any modifications that are required to lab instrumentation, equipment setup requirements, and traditional test processes to allow for testing units using native equipment controls. This will include items such as specifying thermocouple locations, thermistor types, construction of the calibrated box, and synchronization of fans.[15]

RECOMMENDATION:

CLOSELY-SPECIFIED LAB SETUP

- Indicate location & type of sensors
- Synchronize fans

[15] Labs need both high accuracy / slow responding instruments for defensible measured results and less accurate / fast acting instruments to be able to trust primary measurement results when the lab system is not perfectly stable. Consistent measurement locations are also critical to repeatable/reproducible test results in testing units using native equipment controls.

Climate Specific Results

The performance rating procedures for domestic AC/HPs typically specify three things:

1. **Data collection:** what information to collect and how to measure it
2. **Test conditions:** temperatures at which tests are conducted and data are collected
3. **Calculation procedure:** how data are combined into a calculated metric

Data collection includes the type of tests performed as well as the lab and equipment setup and, as discussed above, are critical to *repeatable and reproducible* results.

Test conditions and the calculation procedure are critical for the *representativeness* of any metric. These may vary from region to region and from climate to climate. Past investigation into international AC test methods[16] showed that climate bins used to calculate seasonal efficiency metrics are set at the jurisdictional level and typically have a larger impact on performance ratings than do the actual test conditions.

As part of Phase 2, the research team reached out to stakeholders asking for input on creating a new test procedure that did not involve the calculation procedure, which would allow AHJs to set the procedure and specific temperatures required for any seasonal efficiency metrics to be regionally appropriate. Specific responses from this outreach are included in Appendix 4.

Findings

All respondents supported an approach that did not include the rating procedure. Test points and rating procedures are more appropriately set by local regulators.

Recommendation

The most important aspects of a unified test procedure for variable speed ACs and HPs is the type of tests that are performed and ensuring proper lab and equipment arrangement. The procedure developed in Phase 3 will focus on these aspects, but leaves the test points and rating procedure to the local authorities to define.

RECOMMENDATION:

SPECIFY DATA COLLECTION

- Let AHJ determine Test Points & Rating Procedure

[16] https://www.iea-4e.org/document/442/domestic-air-conditioner-test-standards-and-harmonization

Section 4: Next Steps

This section provides a brief synopsis of the next two phases of this project:

- Phase 3: Development of Guidelines for Load-Based Test Procedure
- Phase 4: Round Robin Trial of Test Procedure

Phase 3: Development of Guidelines

The next phase of this project is to write a unified method of test for variable capacity AC/HPs. The team will use the findings and recommendations from phase 2 to inform the overall approach, along with specifications for lab and equipment setup.

The team will also produce a plan for round robin testing of the test procedure that will be completed in phase 4. This plan will include specifying the characteristics and number of product models to be tested, a proposed timeline, and the requirements of laboratories that will perform the tests.

Phase 3 is scheduled to be complete in November 2021.

Phase 4: Round Robin Testing

In Phase 4, four to six labs will perform round robin testing of the new test method developed in Phase 3. This phase will provide insights into the repeatability and reproducibility of the new test procedure. Countries from 4E will nominate test labs who will submit qualifications and be selected by the research team.

The team will produce a guide to explain the test plan and provide technical support, as well as analyze results from the round robin.

The round robin testing is scheduled to start in December 2021. The report summarizing the findings is scheduled to be complete by December 2022.

Appendix 1: Detailed Phase 2 Test Conditions

Table 7 lists the planned testing for non-ducted HP systems.

Table 7: Non-Ducted System Investigative Test Sequence

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
	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

Test #	Test Name	Description	Method
	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

Table 8 shows the planned testing for ducted HP systems. Tests that are struck-through were not performed. Balance tests were not required for ducted systems because the ducted unit's metering device was located in the indoor unit. Secondary capacity measurement was performed using a refrigerant enthalpy measurement apparatus. Separate energy balance confirmation tests were performed using an outdoor air enthalpy measurement apparatus

Table 8: Ducted System Investigative Test Sequence

Test #	Test Name	Description	Method
1	Control Validation	Control off-set/Control dead-band determination	Indoor Room Enthalpy/Refrigerant Enthalpy
2	Charge Validation	SC targets in both cooling and heating mode	Indoor Room Calorimeter/ Outdoor Air Enthalpy
3	~~Balance 1~~	~~Sensible and latent Cooling~~	~~Indoor Room Calorimeter/ Outdoor Air Enthalpy~~
4	~~Balance 2~~	~~Heating~~	~~Indoor Room Enthalpy/Refrigerant Enthalpy~~
5	Cooling	Base/Default Cooling	Indoor Room Enthalpy/Refrigerant Enthalpy
	5a	High temp (max load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	5b	High temp (rated load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	5c	Median temp (full load)	Indoor Room Enthalpy/Refrigerant Enthalpy

Test #	Test Name	Description	Method
	5d	Median temp (2/3 load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	5e	Median temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	5f	Low temp (full load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	5g	Low temp (2/3 load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	5h	Low temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
6	Heating	Base/Default Heating	Indoor Room Enthalpy/Refrigerant Enthalpy
	6a	High temp (rated load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	6b	High temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	6c	Max temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	6d	Low temp (max load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	6e	Lowest temp (max load)	Indoor Room Enthalpy/Refrigerant Enthalpy
7	Optimized	Cooling Optimized Setting	
	7a	High temp (rated load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	7b	Median temp (2/3 load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	7c	Median temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	7d	Low temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
8	Cyclic	Cooling (sub-min load)	*Transient instruments
	8a	12 cycle test @ F1	Indoor Room Enthalpy/Refrigerant Enthalpy
	8b	12 cycle test @ B1	Indoor Room Enthalpy/Refrigerant Enthalpy
9	CVP	1230 Cooling CVP	
	~~9a~~	~~High temp (rated load)~~	~~Indoor Room Enthalpy/Refrigerant Enthalpy~~

Test #	Test Name	Description	Method
	9b	Median temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy
	9c	Low temp (min load)	Indoor Room Enthalpy/Refrigerant Enthalpy

Appendix 2: Detailed Phase 2 Findings

This section lists the detailed findings from Phase 2 testing. They follow the key issues identified in Phase 1 and listed in Table 9.

Table 9. Findings Pertaining to Key Load-Based Testing Issues

Key Issues	Impact to Investigative Test Plan
Lab Setup / Instrumentation	
• Lab System Control Dynamics	• Prioritize investigation based on manufacturer feedback • Add an internal calorimetric room setup to be able to accurately quantify capacities
• Input Component Bias/Offset	• Not a priority based on feedback from outreach participants • Maintain plans to fully investigate and instrument each test setup to better understand this issue
Equipment Setup	
• Influence of Thermostat	• Prioritize investigation based on manufacturer feedback • Investigate impact of location and equipment using multiple return air thermistor inputs • Do not include third-party thermostats in investigative test
• Test Unit Control Settings	• Prioritize investigation based on feedback from outreach participants • Build out test matrix to include multiple modes of operation, including Dehumidification, Eco Cool, and Eco Heat settings
• Testing Separate Assemblies	• Eliminate from test matrix due to lack of support from outreach participants for testing separate assemblies
• Adaptive Learning Algorithms	• No viable feedback on best practices • Plan to investigate further during Phase 2 testing
Test Approach	
• Load-based Test Concept	• Proceed with compensation target load approach to testing • Investigate approach techniques between test points ○ Monitor and adjust to evaluate test unit control responses during temperature or load transitions • Evaluate test facility and test unit dynamic controls

Key Issues	Impact to Investigative Test Plan
• Calorimetric / Air-Enthalpy	• Proceed with inclusion of both testing methods in load-based test methodology
• Test Burden	• Important issue to manufacturers • Incorporate opportunities to streamline/shorten lab testing of variable capacity equipment into test plan to reduce burden
• System Mapping Approach	• Remove from consideration based on follow-up investigation
• Impact of Climate Region	• Addressed via locally set efficiency calculation procedures • Not included in Phase 2 investigative testing

Lab System Control Dynamics

Laboratory system control dynamics refer to the interaction between the lab setup and the test results. Typical testing requires the lab facility to match the capacity of the UUT at discrete load steps by providing a constant indoor room temperature. Innovative load-based test methods, such as CSA EXP07 and the EN 14511 load-based test guidelines, reverse this testing concept, with the UUT working to match the injected load. This reversal could require changes to the lab system controls to ensure repeatable results.

For sensible loads, the team investigated potential changes to load injection techniques.

Findings

UUT 2 showed aggressive temperature control loops that could not achieve equilibrium when the load was kept constant. This is shown in Figure 13. The unit over-corrected, resulting in temperature swings and power spikes. Figure 14 shows the power consumption at the same conditions.

The lab technicians then manually adjusted the injected load. As they observed the temperature correcting, they either lowered or raised the load and were able to achieve equilibrium. Figure 15 and Figure 16 show this same unit where the injected load was allowed to vary by 3%.

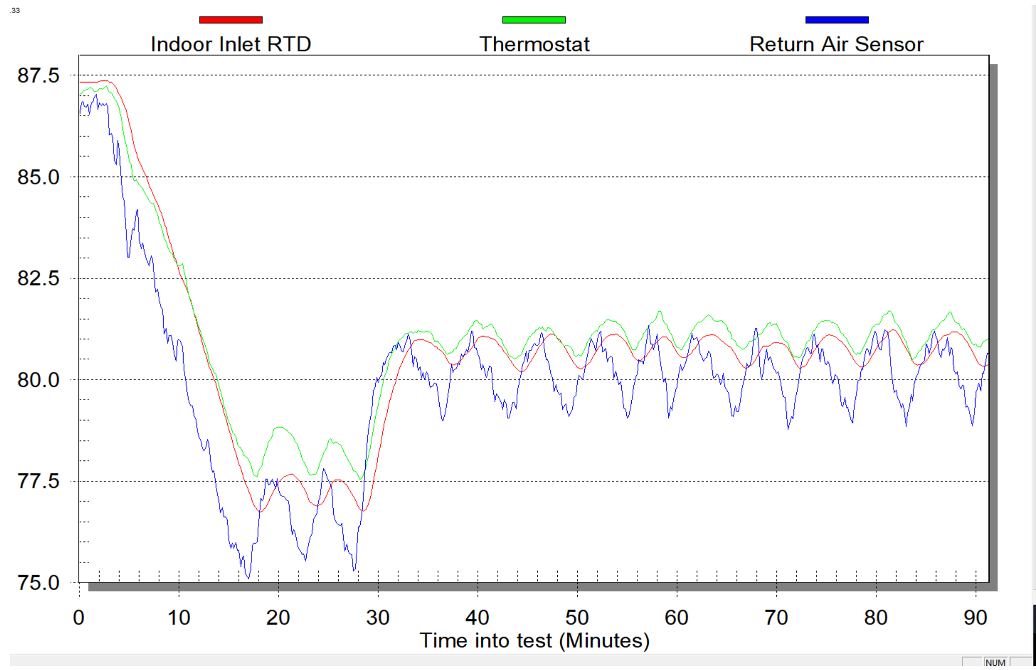


Figure 13. UUT 2 Temperature Cycling During Constant Load Test

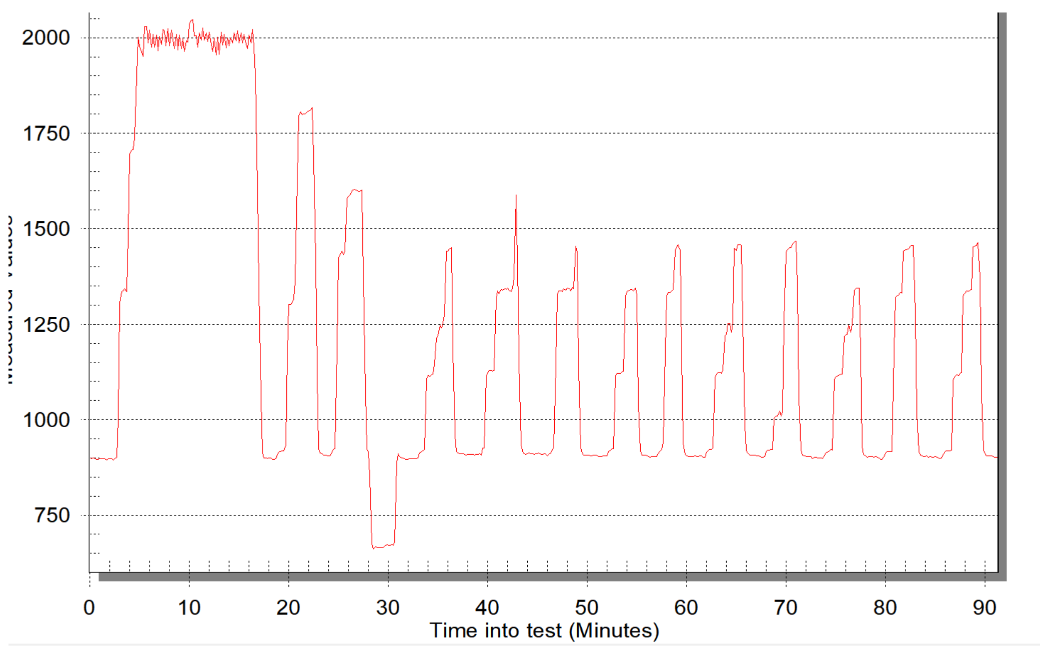


Figure 14. UUT 2 Power Consumption- Cycling During Constant Load Test

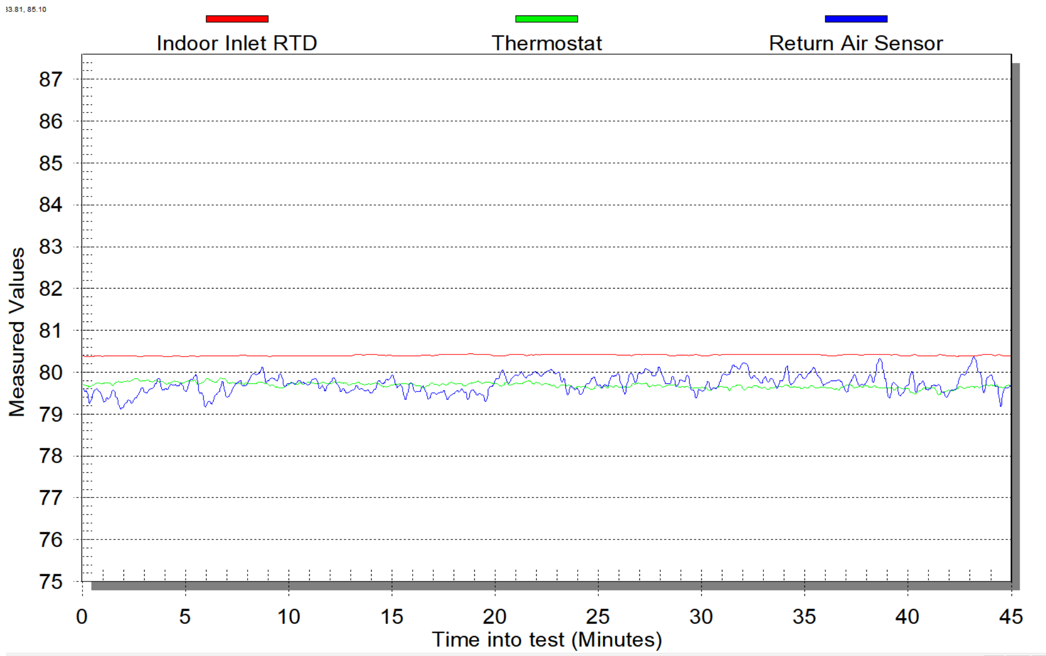


Figure 15. UUT 2 Temperatures- Maintaining Equilibrium During Constant Load Test After Load Tolerance Adjustment

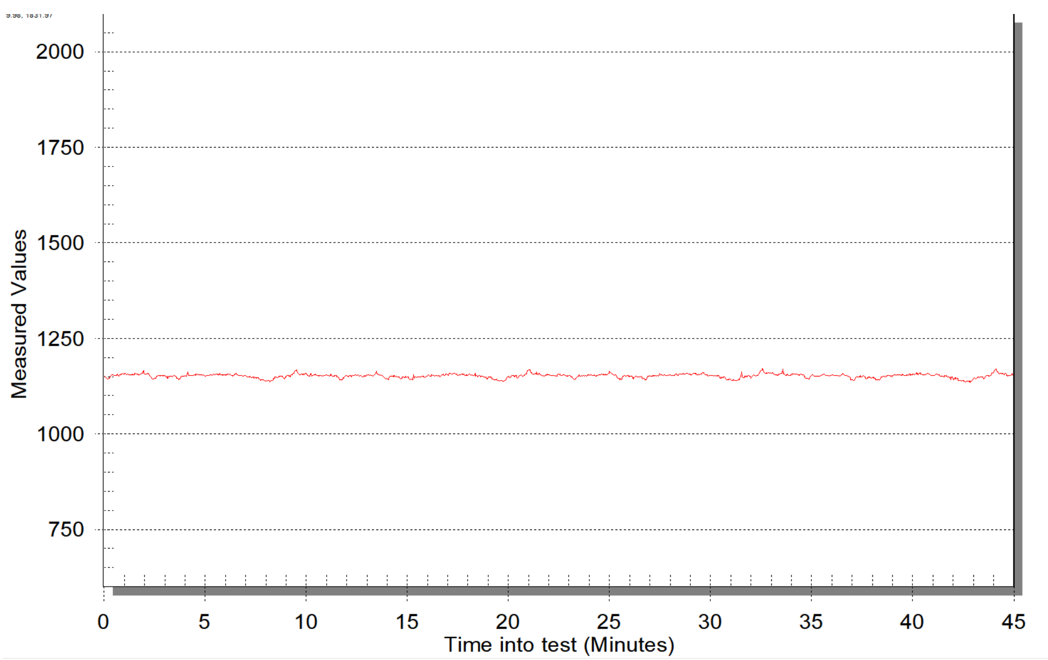


Figure 16. UUT 2 Power Consumption- Maintaining Equilibrium During Constant Load Test After Load Tolerance Adjustment

Conclusions

To make target compensation load viable at a reasonable test burden increase, the tolerances for target load may need to increase. This research showed that, for a limited sampling size, a 3% increase was required. Round robin testing in Phase 4 may provide a more complete picture for a wider variety of units.

Lab System Control Dynamics: Latent Loads

The control of latent loads during load-based testing is particularly challenging, and doubly so when dynamically changing the load.

Findings

The research team tested the units at two separate lab facilities. The labs had different approaches to wet bulb control. One lab contained extra programming that prohibited steam injection until the dry-bulb temperature achieved operating tolerances for at least five minutes. This aided in preventing additional hysteresis due to competing PID loops between the dry bulb and wet bulb control. However, once the test room and equipment achieved equilibrium, both methods were successful in maintaining a reasonably constant latent load injection. Typical labs use independent dry bulb and wet bulb control loops but they interact since the wet bulb is a function of dry bulb and pressure. Also, since the wet bulb injection is typically done with live steam, there is also a considerable amount of sensible heat added that impacts dry bulb control.

Conclusions

Stating criteria for latent control is difficult. The major issue of latent load is in non-steady state testing.

Lab System Control Dynamics- Non-steady state Considerations

Transient conditions occur when a pulse or other temporary phenomenon occur in a system that is not in a steady-state condition. Examples include fan and compressor speed changes. This is separate from a transient state: a state in which a system undergoes a normal change in operation, such as compressor cycling, oil return, or activation of defrost control. Either of these types of transient, non-steady state, considerations could be significant during load-based testing.

In traditional, steady-state testing, fan and compressor speeds are fixed, so this is not a concern. But with load-based testing, the UUT may vary its output, and any lag of measurements can cause an error in capacity measurements.

Findings

The research team found three possible sources for transient error measurement:

1. Non-synchronized lab and UUT fans (air enthalpy method specific) and
2. Size and thermal mass of lab instrumentation
3. Thermal mass of test facility apparatus (duct, sampling tubes, dampers, room size, airflow patterns, etc.)

The typical lab set up does not require synchronizing the UUT and lab fans. This resulted in different energy calculations and introduced uncertainties. Figure 17 and Figure 18 show the difference in instantaneous capacity as calculated with the refrigerant enthalpy method (red data) and air enthalpy method (green data). Inconsistent UUT fan step control and missed "fan off" timing resulted in significant energy balance shifts. Calculations using the refrigerant enthalpy method consistently performed between 4% and 11% higher than air enthalpy method.

The size and mass of sensors can produce a thermal lag and overall response rate where measured temperatures are not in synch with one another. This can have a significant impact on results during non-equilibrium testing.

Figure 19 shows that thermocouples vs resistance temperature detectors (RTDs) aren't the major culprit. The overall shift in Figure 17 and Figure 18 show it has more to do with the airflow synchronization issue. Interestingly, the latent temperatures had a significant delay from the sensible temperatures. That shows up in Figure 18 (when the two lines intersect about 1/3 of the way through the on cycle.) Upon examining the values closely, the latent was actually negative (the psych calculations ignore this and force to zero to eliminate issues with the dry coil cyclic tests they typically run so it wasn't apparent at first glance). Re-evaporation is certainly an issue but the current lab setup will not measure transient moisture changes. Something like a fast acting relative humidity sensor would be needed.

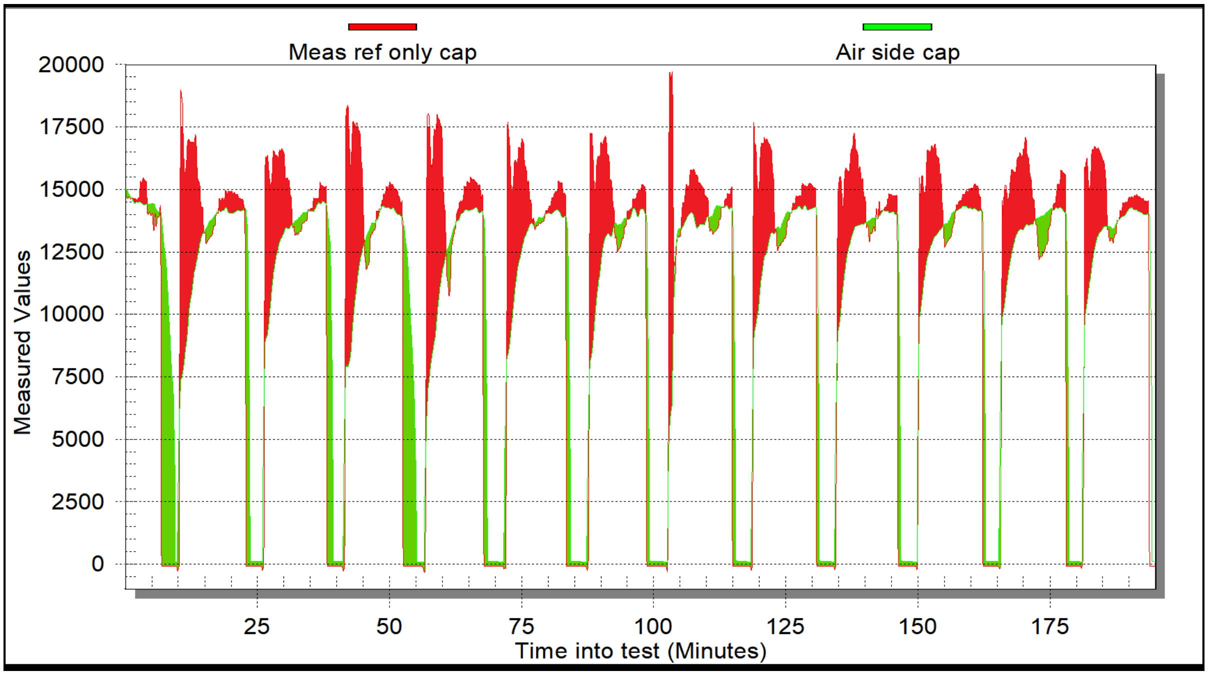


Figure 17. Transient Measurement Shifts

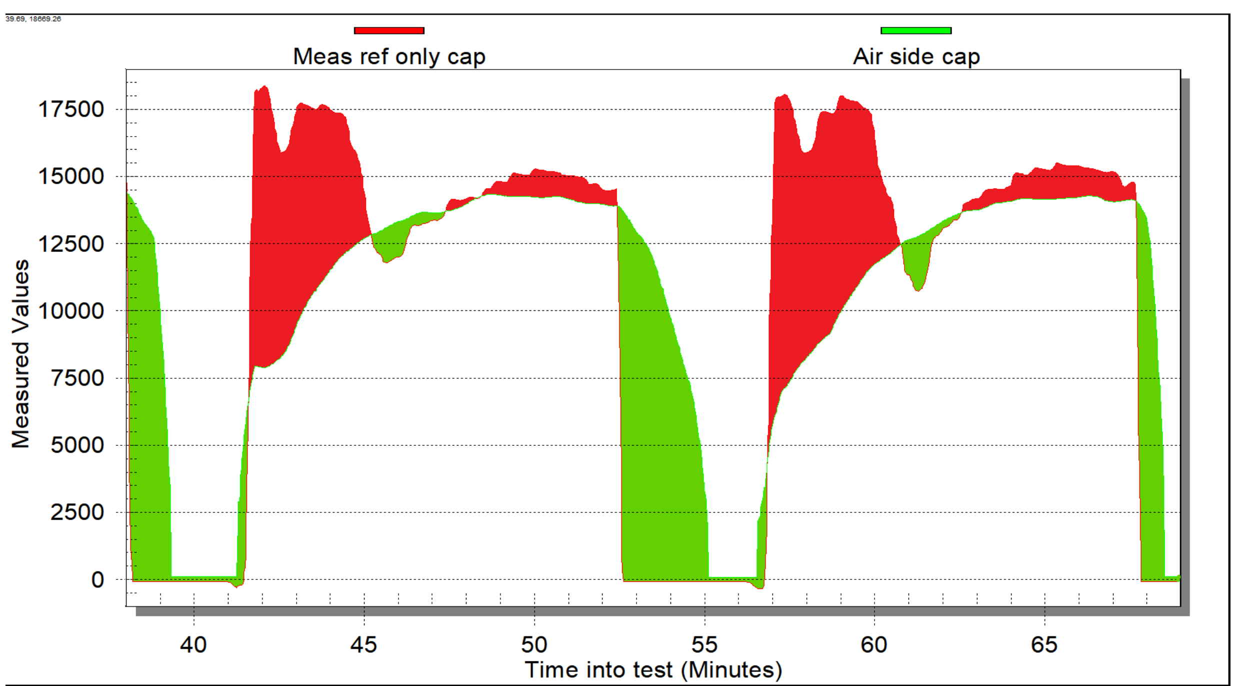


Figure 18. Transient Measurement Shifts (zoomed in)

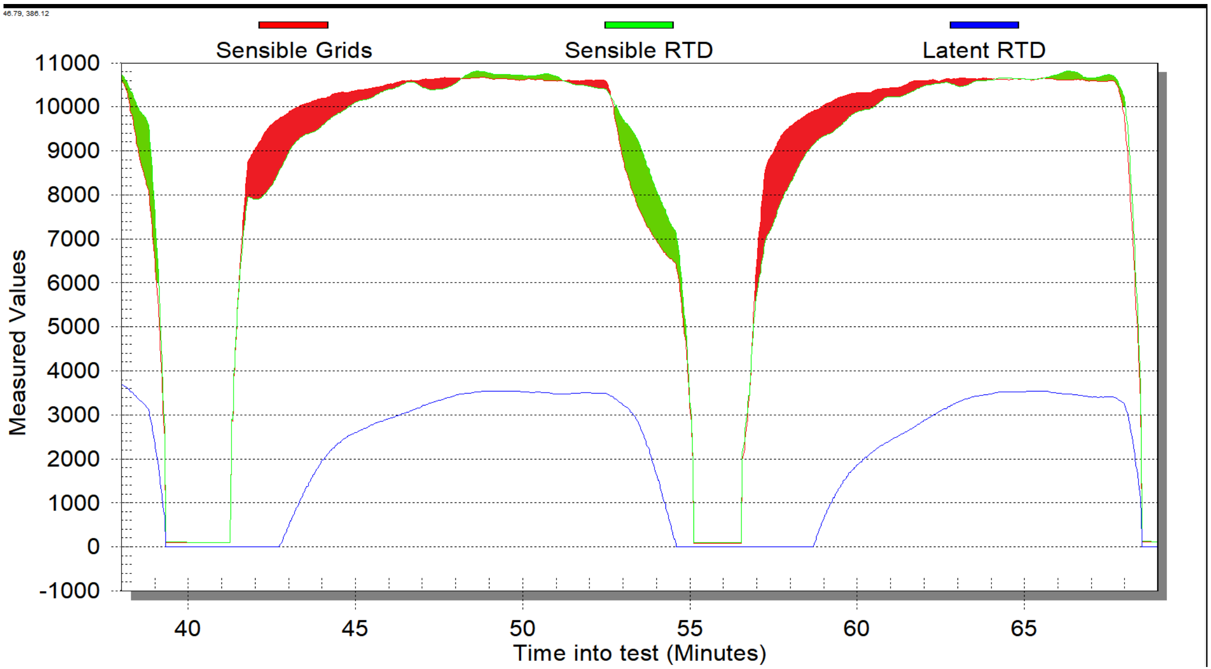


Figure 19. Transient Measurement Shifts (instrumentation)

Conclusions

Thermal lag is a function of the particular test facility size, instrumentation, measurement apparatus and method. Some existing test procedures have developed language to address this issue.[17] However, calorimetric testing for non-ducted equipment does not include any such provision and relies on achieving equilibrium.

Input Component Offset

Input component offset is reviewed in Section 3: Findings & Recommendations under Equipment Setup.

Influence of Thermostat

The thermostat provides the primary input control for AC and HP equipment. Manufacturers typically provide a thermostat in one of three ways: as a remote, as a permanent wall-mounted device, or as an internal return air sensor.

[17] US DOE regulatory test Appendix M1: 3.5 (a) capacity adjustments for thermal mass stored in devices and locations located between measurement points

The team determined that the following aspects of thermostat influence should be further examined during investigative testing:

- Impact of thermostat location on test results
- Methods for testing units with control algorithms relying on more than one return air sensor

Findings

System response is controlled from different sensors for different units. It could be via indoor unit return air thermistor, remote thermistor, or a wired thermostat.

- Unit 1 (non-ducted) allowed return air thermistor, remote thermistor, or a combination of the two (selected by the user)
- Unit 2 (non-ducted) only allowed return air thermistor
- Unit 3 (ducted) only allowed wired thermostat thermistor

Conclusions

If the test lab understands which sensor is the controlling sensor, and the chamber is uniformly mixed, test results are valid.

Feedback sensors are different from ducted and non-ducted equipment. This suggests using an alternative test method for non-ducted and ducted AC/HP equipment.

Test Unit Control Settings

The test unit control settings are discussed in Section 3: Findings & Recommendations: Equipment Setup.

Adaptive Learning

Variable capacity ACs and HPs often include adaptive learning control algorithms, which require a minimum period of time for learning or tuning the algorithm. Some brands list this tuning period as a requirement to achieve rated efficiency levels. The research team asked Phase 1 outreach participants for feedback on specifics of these adaptive controls but received little or no input.

An investigation of adaptive learning could take weeks or months of in-lab study. This is outside the scope of this project and was not studied in Phase 2.

Load-Based Test Concept

The load-based test concept is discussed in Section 3: Findings & Recommendation: Load-Based Test Concept.

Method of Test Measurement: Calorimetric vs Air-Enthalpy

As determined in Phase 1, measuring AC and HP capacity is traditionally done using one of the following methods of test measurement:

- Calorimetric (capacity based on balancing the space conditioning produced by the UUT against the measured heating/cooling and water energy inputs)
- Psychrometric (capacity based on enthalpy measured at the inlet and outlet of the equipment and mass flow of the air/refrigerant)

Phase 1 polling of outreach participants found overwhelming support to include both test measurement approaches to better align with global measurement approaches. Therefore, in Phase 2 testing, non-ducted test units were tested using both test measurement methods while the ducted unit was tested using only the psychrometric test measurement approach. The following sections explain the reasoning for this and describes each measurement approach in more detail.

Non-ducted Systems

Non-ducted units are typically tested in a calorimetric chamber across Europe and Asia. However, they are more commonly tested in psychrometric chambers in North America. When testing non-ducted systems in a psychrometric chamber where ductwork is connected, precautions are required to avoid issues such as influencing the air properties by interfering with the supply and return air paths or influencing the air volume rate/fan power due to interactions with the airflow measurement apparatus.

The majority of investigative testing of non-ducted systems in Phase 2 utilized a hybrid of both calorimetric and psychrometric measurements. This hybrid method was used in order to replicate a room calorimetry approach on the indoor side for primary capacity measurement-eliminating the potential issues when attaching ductwork and airflow measurement apparatus. The hybrid test facility was a modified psychrometric room that included a calibrated box on the indoor side and employed an outdoor air measurement apparatus to allow for an energy balance confirmation at full load in both cooling and heating modes. The hybrid “box” was fully calibrated per ASHRAE Standard 16 prior to conducting investigative testing. This non-ducted lab setup is shown in Figure 20.

Limited validation tests using psychrometric methods were also conducted at specific load points.

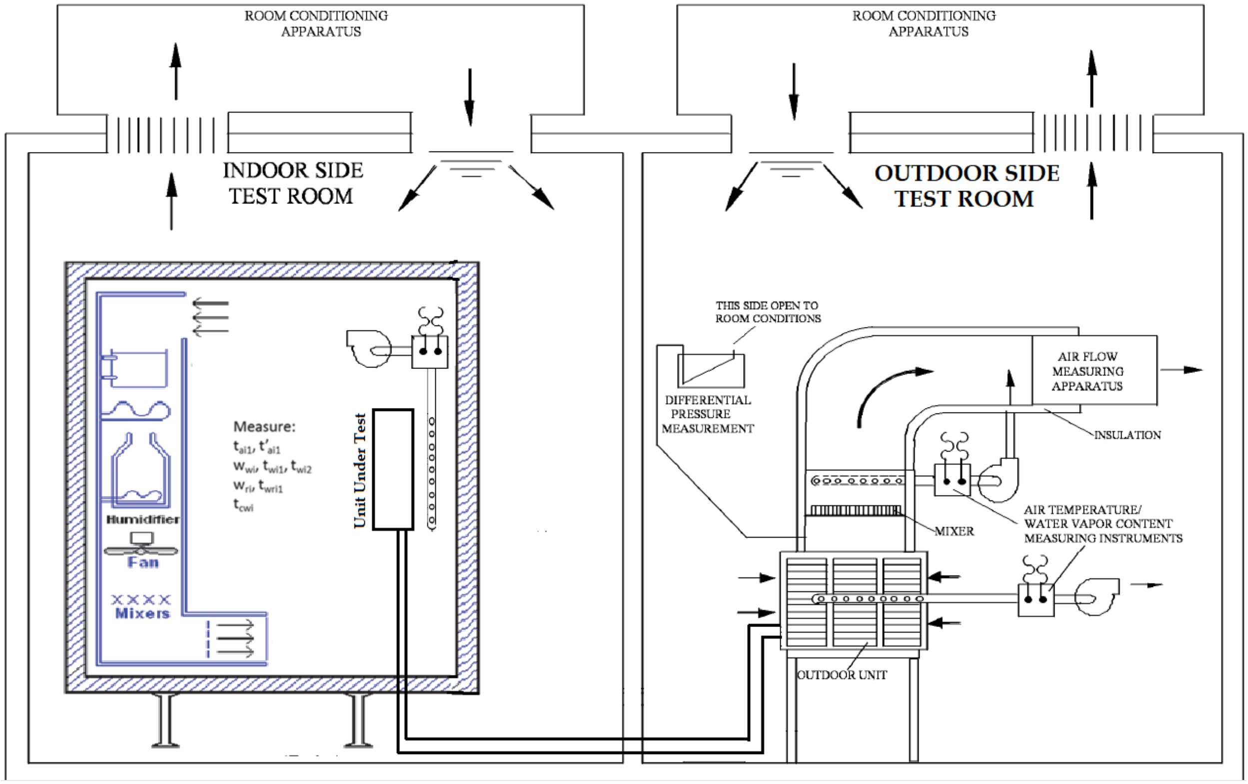


Figure 20. Non-ducted Lab Setup Showing Indoor Calibrated Box within Psychrometric Room

Ducted System

The ducted system was evaluated in a standard psychrometric facility with modified parameters to allow for manual control of sensible and latent loads. This manual load control differs from current steady-state test procedures, but is necessary to achieve the changing loads needed for load-based testing. Indoor air enthalpy was used as a primary method for capacity determination. The refrigerant enthalpy method was used as a secondary capacity determination when the metering device was located in the indoor section. Alternatively, the outdoor air enthalpy method was used to confirm energy balance at full load cooling and heating operation.

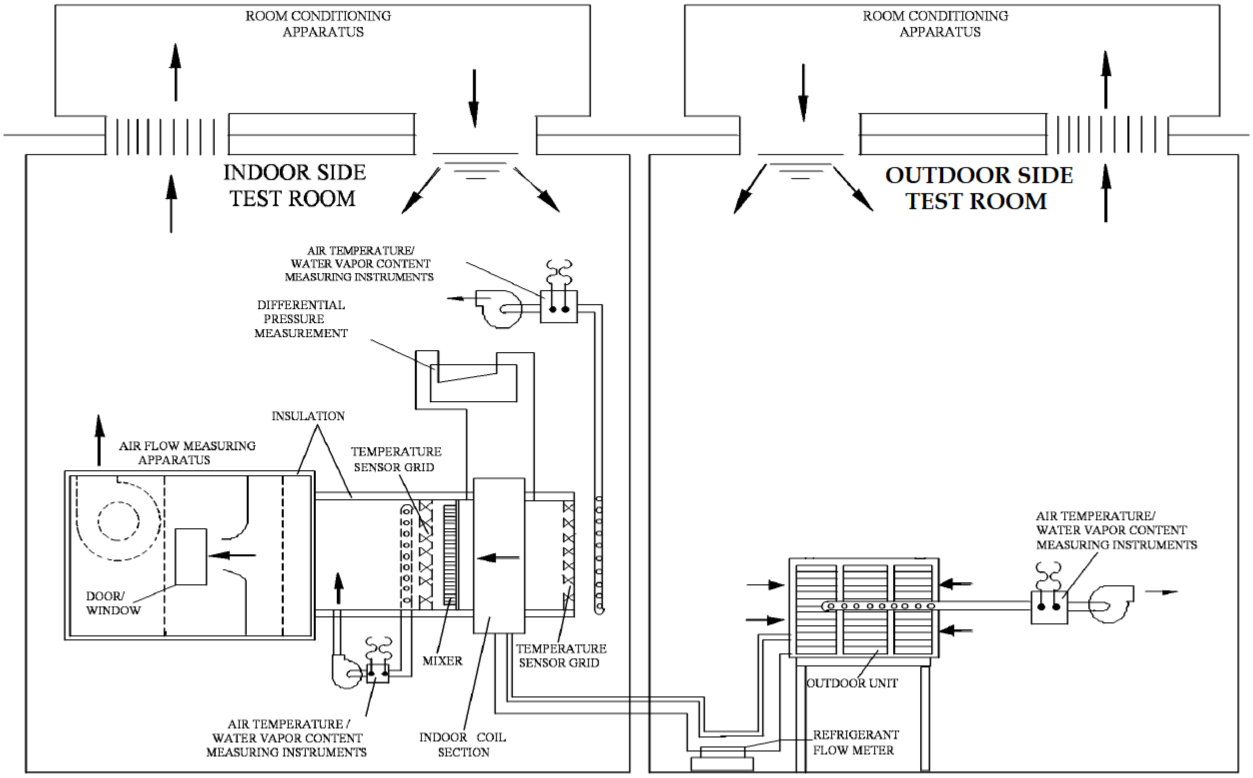


Figure 21. Indoor Air Enthalpy/Refrigerant Enthalpy Method[18]

Findings

In general, there was a relatively strong agreement between the calorimetric and psychrometric test results for the non-ducted units. However, at median temperatures and minimum loads, capacity varied by as much as 22.5% and COP varied by as much as 10.6%. The ducted unit also performed similarly between two different psychrometric facilities. These results are shown in Figure 22, Figure 23, and Figure 24. The A2 tests are full load cooling at 95°F (35°C). The B1 test is minimum load cooling at 82°F (27.8°C). H1N shows nominal load heating at 47°F (8.3°C), H11 shows minimum load heating at 47°F, and H42 shows full load heating at 5°F (-15°C).

However, there were two anomalies. The manufacturer publicly provides only the full load cooling and heating targets. The test plan then requires the test laboratory to determine the minimum stable load via testing for both median and low temperature. The research team observed a capacity variation of up to 22.6% between test laboratories at the heating mode median temperature minimum load test point. One theory that may explain this anomaly is that psychrometric tests prevent recirculation of discharge air to the return. This recirculated air could lead to more frequent compressor off cycles, which would require the test laboratory to increase the load to allow for steady-state operation.

[18] Source: ASHRAE 37-2009 (Figure 1)

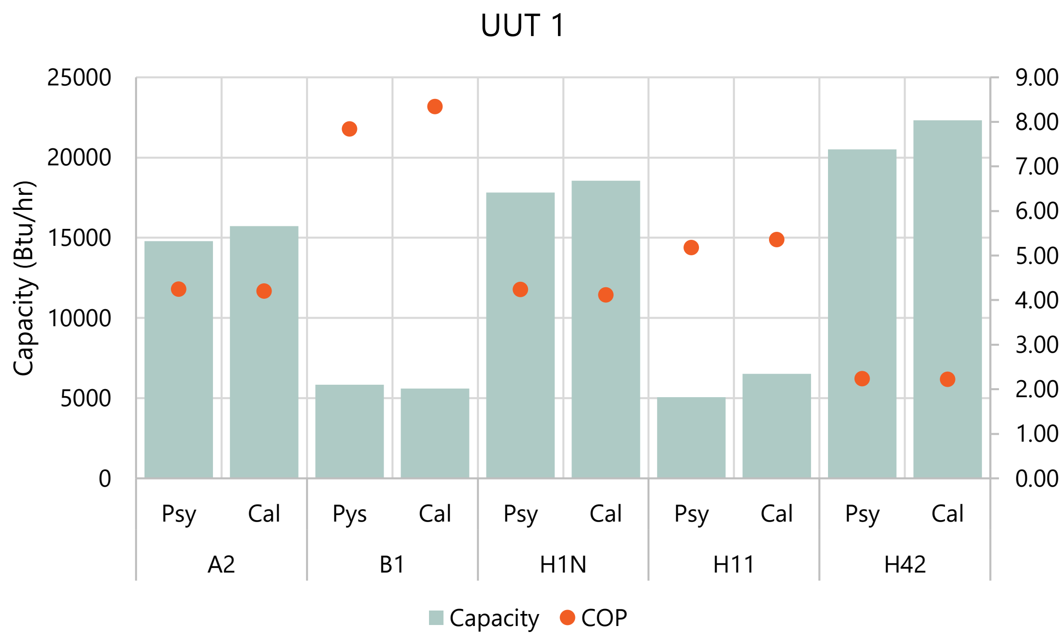


Figure 22. UUT 1 Comparison of Capacity & COP Calculations Made by Psychrometric and Calorimetric Methods at Different Test Conditions

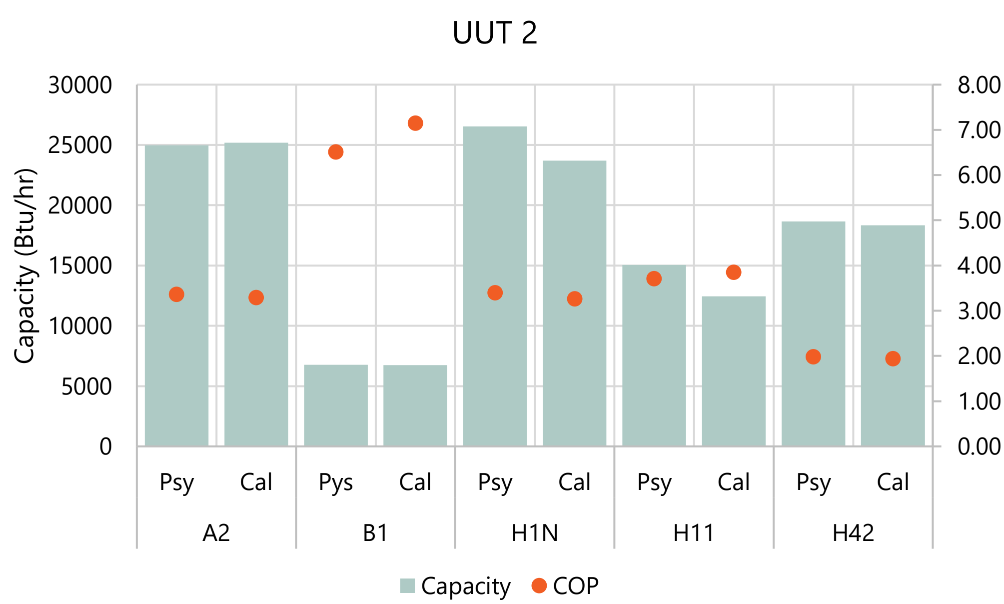


Figure 23. UUT 2 Comparison of Capacity & COP Calculations Made by Psychrometric and Calorimetric Methods at Different Test Conditions

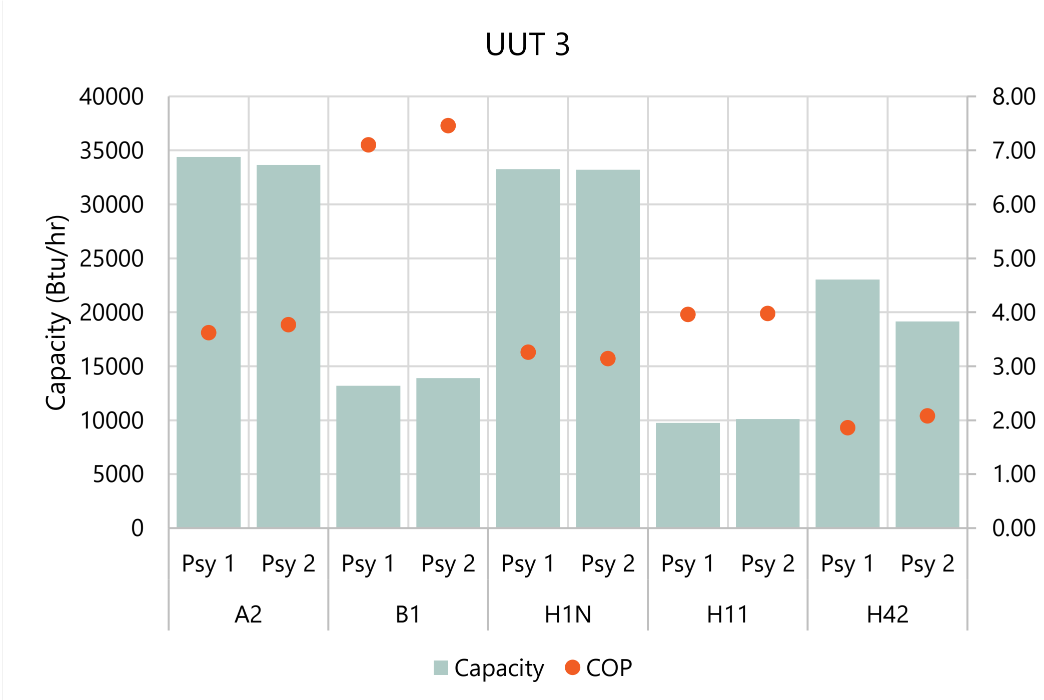


Figure 24. UUT 3 Comparison of Capacity & COP Calculations Made at Two Different Psychrometric Facilities at Different Test Conditions

Conclusions

While both methods can yield valid results for target compensation load-based tests, the anomalies observed at the minimum loads reinforce the research team's recommendation that non-ducted units be tested in calorimetric chambers. As described in Section 3: Findings & Recommendations- Non-ducted Unit Testing, the additional duct work and air measurement apparatus, coupled with the spot cooling effect, sliding thermostat, and recirculation impacts for non-ducted units, causes calorimetric testing to be most representative.

Test Approach: Test Burden

Test burden is discussed in Section 3: Findings & Conclusions- Load-Based Test Concept. An overview is given in Table 4.

Impact of Climate Region on Results

The impact of climate region is discussed in Section 3: Findings & Recommendations- Climate Specific Results.

Appendix 3: Outlined Test Method Approach- Phase 3

1. Purpose
    a. To provide a uniform method of test and calculations for residential air conditioners and heat pumps with variable speed compressors
2. Scope
    a. TBD - Define power source, heat rejection source(s), minimum unit configurations and capacity limitations
3. Nomenclature/Definitions
4. Unit Classification/Configurations (TBD)

<table>
<tr><th>Configuration</th><th>Heat Rejection</th><th colspan="2">Indoor Arrangement</th></tr>
<tr><td rowspan="4">Single Package System & Single Split System</td><td rowspan="2">Air Cooled</td><td rowspan="4">Blower Coil</td><td>Ducted</td></tr>
<tr><td>Non-ducted</td></tr>
<tr><td rowspan="2">Air Source</td><td>Ducted</td></tr>
<tr><td>Non-ducted</td></tr>
</table>

5. Instruments and Measurements
    a. General Accuracy
    b. Electrical
    c. Temperature
    d. Water Vapor Content
    e. Pressure
    f. Flow
    g. Rotational Speed
    h. Time
    i. Mass
6. Test Methods Applicability
    a. Indoor Air Enthalpy
    b. Outdoor Air Enthalpy
    c. Indoor Calorimeter
    d. Outdoor Calorimeter
    e. Refrigerant Enthalpy
    f. Outdoor Liquid Coil
    g. Compressor Calibration
7. Test Room Requirements and Measurement Arrangements
    a. Indoor Arrangement
    b. Outdoor Arrangement

    c. Air property measurement
    d. Plenum and ducting
    e. Static pressure
    f. Liquid other than refrigerant
    g. Refrigerant

8. Test Procedures
    a. Test Unit Configuration (rating standard dependent)
    b. Control Validation
    c. Compensation Target Load
    d. Equilibrium/Steady State tests
    e. Transient/Modulating or Cycling tests
    f. Operating and Condition Tolerances
9. Calculations
10. Symbols and subscripts
11. Data Recording and reporting requirements
12. References

Appendix 4: Comments from Consultees

At the conclusion of Phase 2, the research team released preliminary results and requested comments from stakeholders who have been engaged in this research.

The table below summarizes their comments.

IEA 4E Phase 2 Comment Matrix Summary

Issue	Comment Summary	Recommendation
Test Concept (Question 1)	7 commenter(s) supported the development/adoption of target load compensation 4 commenters supported adoption of CSA EXP-07 with minor modifications. 1 commenter voiced concerns with departing from existing methods for any "non-fixed" tests. 2 commenters supported the use of a CVP as an important interim step until a dynamic/simulated use test is developed. 2 commenter(s) supported immediate development/adoption of existing dynamic/simulated use test.	Utilize a target load compensation method as a controls verification procedure to validate system performance and operation at any test/load condition specified by the AHJ scheme where compressor speed or other modulating components are manually overridden for the test. • The test unit is operated under native controls • The compensation load on the indoor side is determined from the test condition of the outdoor side and the simulated building performance/load line. • The compensation loads are dynamically controlled to achieve equilibrium with the test unit
Allowable Tolerance Increase (Question 2)	4 commenters stated no tolerance increase is preferred. 1 commenter supported the suggested doubling of condition tolerances but did not comment on R&R tolerances.	Maintain existing test condition, test operating and R&R tolerances for existing regulatory tests. For the target load compensation verification procedure, increase condition tolerances to allow for variation in test unit controls.

	1 commenter supported increasing the R&R tolerances to 10%. The remaining commenters either did not respond to this question or did not provide a specific percentage increase.	
Maximum allowable test burden increase (Question 3)	4 commenters supported an increase up to 25% 1 commenter stated they would not support any additional burden. 2 commenters supported an increase up to 50% The remaining commenters either did not respond to this question or stated conditional support for an unspecified burden increase.	By utilizing the target load compensation method as a controls verification, the burden will depend on how many test points will be validated. Each controls verification would add 1-4 hours (up to 6% per test point).
Rating Procedure Agnostic (Question 4)	All 7 of the commenters that responded to this question supported a rating procedure agnostic approach.	Develop the target load compensation controls verification procedure to apply to any given test/load condition specified by the AHJ . Reference the AHJ for test system configuration, application specific settings, etc.