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AC/HP Test Methods 2.0:

Phase 1 Findings Summary

IEA/4E

Developed For

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Executive Summary

Variable capacity air conditioners (ACs) and heat pumps (HPs) have become increasingly popular around the globe. However, testing variable capacity units presents significant challenges for manufacturers and regulators. Work is underway in several regions to develop new load-based test methods for these products that address some of these challenges, but no consistent and coordinated consensus-based method has yet emerged. Recognizing this, the International Energy Agency Energy Efficient End-Use Equipment (IEA/4E) commissioned a four-phase research project to develop an international load-based test procedure for residentially sized variable capacity AC and HP equipment. Phase 1 of this work centers around an investigation of identified challenges or "key issues" related to load-based testing of variable capacity ACs and HPs. This report documents the team's findings for the project's initial phase, which included an investigation of existing innovative test methods and outreach to interested parties to inform and/or build on a set of known key issues with load-based testing. The goals of the Phase 1 research include:

1 | Determine whether existing load-based test procedures and recent research findings inform the key issues previously identified in the 4E RFQ.
2 | Consult with testing and industry professionals to determine whether there is new research or additional key issues that should be considered.
3 | Utilize these findings to develop an investigative test plan, which will be carried out as Phase 2 of this project.

The research team grouped the identified key issues into several categories for investigation, including lab setup and instrumentation, equipment setup, test approach, and the impact of climate region on the test results. While the methodology and detailed findings of the Phase 1 investigation are presented in the body of this report, the key takeaways with respect to the identified challenges to testing are summarized in Table 1.

Table 1: Findings pertaining to Key Load-Based Testing Issues

Key Issue	Findings
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

Key Issue	Findings
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 shared 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 • Evaluate test facility and test unit dynamic controls
• 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

The team used the above findings to develop a detailed Investigative Test Plan to further investigate the remaining issues with load-based testing. The detailed test plan is included as Appendix 2 of this report, with testing to be carried out in the coming months.

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Section 1 Introduction

Across the globe there are numerous governing bodies that currently test and regulate air conditioners (ACs) and heat pumps (HPs), and more than 60 countries have regulatory requirements on their energy performance. Testing and regulation of performance metrics are proven, cost-effective strategies for slowing the growth of energy consumption and reducing peak demand on electrical systems around the world.

As residential AC and HP equipment has continued to advance, manufacturers have introduced and promoted variable capacity, or "inverter-driven", equipment as the most efficient options available on the market. However, the testing of these increasingly popular variable capacity ACs and HPs has presented significant challenges for manufacturers and regulators. Work is underway in several regions to develop new load-based methods for testing these products with the goal of ensuring test procedures and metrics are representative of field control and performance. AC and HP test procedures currently used for equipment regulatory purposes have the commonality of locking compressor performance at fixed speeds. While this approach yields a snapshot of performance at that operating speed or load output, it does not account for the modulating nature of the native equipment controls.

A recent examination of current international test procedures and metrics 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.[1] 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.

1.1 Research Overview and Goals

The current research reviews innovative test procedures for variable capacity ACs and HPs in order to develop an internationally applicable load-based test method for the equipment. The research team will complete four phases of research activity:

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

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

This summary of findings pertains to Phase 1: Investigate Innovative Test Methods. The goals of this phase of research are three-fold:

1 | Determine whether existing load-based test procedures and recent research findings inform the key issues previously identified in the 4E RFQ.
2 | Consult with testing and industry professionals to determine whether there is new research that should be considered.
3 | Utilize these findings to develop an investigative test plan, which will be carried out as Phase 2 of this project.

The research team has grouped the identified challenges, or "key issues", related to load-based testing of variable capacity ACs and HPs into four main categories:

1. Lab setup and instrumentation issues
    - Lab System Control Dynamics
    - Input Component Offset and Bias
2. Equipment setup issues
    - Thermostat Influence
    - Test Unit Control Settings
    - Testing Separate Assemblies
    - Adaptive Learning Algorithms
3. Test approach issues
    - Load-based Testing Concept
    - Calorimetric vs Air-Enthalpy Test Method
    - Test Burden
    - System Mapping Approach
4. Impact of climate region on results

These key issues have the potential to impact the test burden, repeatability, reproducibility, and representativeness of an international load-based test procedure and are explored in depth in Section 3 of this report.

1.2 Research Approach

Phase 1 of the research centered on the investigation of recent developments in variable capacity testing. The research team took a two-pronged approach to this investigation, first performing a literature-based review of the existing body of research, including innovative testing methods, followed by outreach to industry professionals to discuss the identified key issues with those knowledgeable about AC and HP performance.

1.2.1 Investigation of Innovative Test Methods

The research team investigated current and developmental load-based test methods for variable capacity ACs and HPs to determine how each test method addresses the identified key issues, and whether current research findings further address those key issues. The innovative test methods considered by the research team includes:

- Canadian Standards Association (CSA) EXP07: Load-Based and Climate-Specific Testing and Rating Procedures for Heat Pumps and Air Conditioners
- European Standard EN 14511: Air conditioners, liquid chilling packages, and heat pumps with electrically driven compressors for space heating and cooling
    - Including Test Guideline for Dynamic Performance Testing and Calculation of the Seasonal Coefficient of Performance for Heat Pumps
    - Published by Bundesanstalt für Materialforshung und prüfung (BAM)
- Air-Conditioning, Heating, & Refrigeration Institute (AHRI) Standard 1230: Performance Rating of Variable Refrigerant Flow (VRF)
    - Including proposed Controls Verification Protocol (CVP)
    - JIS 8616 included by way of reference

In addition, the research team reviewed existing research into variable capacity AC and HP testing to further inform the details behind the key issues identified in the project scope. These recent research reports include:

Table 2: Current Research Activity in Load-Based Testing

Research/Documentation	Title / Description
2018 Purdue research papers	2709 – Load-based Testing Methodology 2710 – Performance evaluation of VSHP 2713 – Virtual model and T-stat impacts 2544 – Setup impacts on cyclic degradation
Next Gen Rating Methods Presentations and Meetings	AHRI working group (3R's testing) "Connected" products NRCan and PG&E Field testing
NEEA EXP07:19 Report NEEA E11-225 Report	Interim Lab Testing and Rating Results Ductless Heat Pump Impact & Process Evaluation: Lab Test Report
ACRA2018-E342	Experimental Comparison using simulated heat flux conditions
Energies 2019	Fixing Efficiency Values by Unfixing Compressor Speed

ACEEE Study on Energy Efficiency	Performance Testing of Variable Capacity Heat Pumps in the Pacific Northwest
BAM Test Guidelines for Dynamic Performance Testing	Guidelines for Testing Heat Pumps with Electronically Driven Compressor for Space Heating

The research team referenced this body of work to help inform an initial approach and to understand each identified key issue.

1.2.2 Outreach to Knowledgeable Parties

Following the initial review of innovative test methods, the team held two forums with industry organizations. The purpose of the outreach forums was to share current understanding of the key issues, solicit feedback on any gaps in understanding, and determine whether there were additional key issues that required investigation. The team followed up on items that warranted further discussion after the outreach forums with direct phone calls. Table 3 is a summary of the organizations represented in the outreach forums. A complete list of outreach activity is included as Appendix 1. The complete list also includes those parties that were contacted without successful response.

Table 3: Outreach Forum Representation

Technical Forum		Manufacturer Forum	
Organization	**Country**	**Organization**	**Country**
BAM	Germany	AHRI	US
RiSE	Sweden	EPEE	EU
NRCAN	Canada	HRAI	Canada
BKR Energy	Canada	Eurovent	EU
Inst Energy Economics	Japan	China NIS	China
Purdue Labs	US	Japan IEE	Japan
Intertek Labs	US	Daikin Group	US
UL Labs	US	Daikin Group	Japan
US DOE	US	Mitsubishi	US
NEEA	US	Mitsubishi	Japan
PG&E	US		
2050 Partners	US		

Both forums served as means to share the research team's initial findings regarding key investigative testing issues and determine whether the group had new information that had not yet been considered. The manufacturer forum was also used to gauge the impact of testing concepts to manufacturers and determine industry barriers to new test procedures.

Section 2 discusses the research team's findings on innovative test methods. In Section 3, the research team leverages outreach findings to prioritize and refine the key issues for investigative testing. Section 4 presents conclusions and next steps, including the development of an investigative test plan to inform Phase 2 testing. The full Phase 2 Investigative Test Plan is included as Appendix 2.

Section 2 Innovative Test Methods

The team examined existing innovative test methods employing load-based test procedures to identify international applicability and determine best practices and approaches. The reviewed test methods include:

- CSA EXP07
- EN 14511 with BAM / RiSE load-based testing procedure
- AHRI 1230 Controls Verification Protocol (CVP)

A high-level summary of these innovative test methods is presented in Table 4.

Table 4: Innovative Test Methods Summary Comparison

Test Method	Description	Benefits	Challenges
CSA EXP07	• Target Compensation load-based approach with elements of dynamic testing	• Air-enthalpy test method allows for a larger range of capacity • Attempts to capture performance representative of field installation	• Humidity response approach is difficult to achieve in lab • Initial repeatability results indicate challenges with TP ambiguities. • Only includes air-enthalpy test approach
EN 14511 (BAM / RiSE load-based test)	• Compensation load-based approach	• Longest used load-based test procedure • Room humidity is easier to control using calorimetric test approach	• Procedure only includes calorimetric test approach • Limited to 12kW (3.4 Tons) capacity • Highest test burden
AHRI 1230 CVP	• Dynamic test that verifies control response of variable capacity heat pumps	• Manufacturers appear to be more accepting of controls verification protocol approach due to perceived lower burden and impact to current rating procedure • Lowest test burden	• Applies to VRF as written, so many portions are not applicable to room ACs and HPs

A more detailed summary of each test method follows. A detailed description of target compensation load and dynamic load test concepts is included in Section 3.3.1.

2.1 CSA EXP07

The CSA EXP07 test method is a target compensation load-based approach which incorporates elements of dynamic testing and uses an air-enthalpy measurement approach. This means the air inlet and outlet conditions are measured directly at the indoor fan coil unit. The test attempts to capture performance representative of field installation by using the equipment's native controls to respond to a simulated test load imparted onto the test chamber. This test has completed some round robin test series with additional round robin testing being conducted currently. Field test and monitoring to show field to lab comparisons is slated for 2021.

The EXP07 method presents several challenges that will potentially impact repeatability. The humidity response required to conduct the test profile will be difficult to control in a laboratory setting, and therefore lab to lab repeatability may be difficult to achieve based on each laboratory's ability to control humidity. This method does not address testing details such as how to approach test setpoint temperature, fan coil louver settings, and which operation mode and other unit settings to select during testing. These are known to contribute to repeatability issues in existing steady state test procedures and will certainly be a factor in load-based testing.

2.2 EN 14511 with BAM / RiSE Load-Based Test

The EN 14511 test method is a compensation load-based test procedure where the indoor room is subjected to a simulated building load and the AC or HP to be tested responds accordingly as it tries to maintain the desired indoor conditions, while outdoor room conditions are held constant. This test uses a calorimetric test measurement approach that involves measuring the energy input to the equipment serving a known load injected into the conditioned room, as opposed to measuring air inlet and outlet conditions directly.

The EN 14511 method is currently undergoing round robin test trials, which makes reproducibility undetermined at this time. With several days required to complete the full test series, the length of time to conduct this test procedure is the longest of the load-based test procedures. The calorimeter test approach enables the humidity to be controlled easier than a psychrometric approach, however because the procedure only allows for calorimeter testing, the capacity of the unit under test is limited to less than approximately 12kW (3.4 Tons).

2.3 AHRI 1230 CVP

The AHRI 1230 CVP test method includes both a steady-state performance test and a dynamic test protocol that verifies the control response of variable refrigerant flow (VRF) multi-split ACs and HPs. The controls verification procedure used in AHRI 1230 validates the ability of the control system to achieve the manufacturer specified settings used in steady-state performance evaluation and has broad manufacturer support. However, in its current form, AHRI 1230 was written specifically for VRF systems, and many aspects of this procedure are not applicable to room ACs and HPs.

Section 3 Investigation of Key Issues

During exploration of load-based test procedure possibilities, the research team identified a set of key issues needing further investigation. These key issues all have the potential to impact the repeatability, reproducibility, and representativeness of an international load-based test method. As noted previously, the research team has grouped the key issues into four main categories:

1. Lab setup and instrumentation issues
    - Lab System Control Dynamics
    - Input Component Offset and Bias
2. Equipment setup issues
    - Thermostat Influence
    - Test Unit Control Settings
    - Testing Separate Assemblies
    - Adaptive Learning Algorithms
3. Test approach issues
    - Load-based Testing Concept
    - Calorimetric vs Air-Enthalpy Test Method
    - Test Burden
    - System Mapping Approach
4. Impact of climate region on results

Each group is further broken out and explored in depth in the following sections.

3.1 Lab Setup and Instrumentation Issues

Lab setup and instrumentation issues include those specific to whether the lab is equipped to carry out the AC or HP performance testing. The key issues identified in this category include lab system control dynamics and input component offset and bias. Polling during outreach to manufacturers indicated that laboratory system control dynamics is a top priority for further investigation.

3.1.1 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 respond and match the load of the test unit capacity at discrete load steps.

Innovative load-based test methods, such as CSA EXP07 and the EN 14511 load-based test guidelines reverse the typical testing concept, with the test unit working to match the injected load. This requires changes to the lab capabilities to ensure repeatable results.

Table 5 shows the lab system control capabilities the team plans to investigate during investigative testing to be able to address requirements for repeatable load-based testing.

Table 5: Further Investigation of Lab System Control Dynamics

Lab System Control Requirement	Comments
Sensible loads	• Are changes required to sensible load injection techniques to maintain lab outdoor air and room conditions?
Latent loads	• Is the current method of steam injection for latent load control in air-enthalpy test setup responsive enough to maintain a constant latent load in the test room? • How can testing issues with the CSA EXP07 approach of collecting room humidity as a dependent variable be resolved?
Considerations for transient tests	• Which portions of the measurement apparatus require existing test methods to reach equilibrium to achieve accurate results? • Is defining a steadily repeating cycle a workable solution for variable speed equipment that exhibits cyclic behavior?
Characterization of facility heat transfer, leakage, and thermal mass	• Calorimetric room facility heat transfer is precisely defined, and load-based testing using this method has shown repeatable results. What impact does this characterization have on test results that use an air-enthalpy approach?
Retune of PID control settings for faster response leads to less stable control	• Outreach participants indicated that some increase to tolerances would be acceptable. What are appropriate targets for lab repeatability/reproducibility?

Outreach discussions showed consensus that control of latent loads and characterization of facility heat transfer are particularly challenging to address in an air-enthalpy test arrangement. Because of this, the team plans to develop a hybrid test configuration to definitively address these questions during investigative testing.

3.1.2 Input Component Offset and Bias

The primary control input for residential ACs and HPs is the return air thermistor in nearly all known test units. Laboratory findings have shown that some manufacturers introduce an offset or bias in the return air thermistor 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 70ºF / 21ºC return air temperature, even if the thermostat is set to 69ºF. 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.[2] This is a best practice that the research team will continue with newly developed test guidelines.

ACs and HPs—specifically those with variable capacity capability—use multiple control loops that operate simultaneously to constrain unit operation rather than strict reliance on return air temperature, which 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.

The research team polled manufacturer outreach participants on whether test methods should consider the offset and bias of inputs other than the return air thermistor. Polling results showed that considering additional input offset/bias is a low priority to AC and HP manufacturers. However, the team will pursue additional understanding of whether additional input offset/bias impact unit control during testing and how this affects performance and repeatability results.

The team plans to fully instrument each unit under test during investigative testing to identify offset/bias and observe where these are impactful to results.

3.1.3 Lab Setup and Instrumentation Next Steps

The team found that lab system control dynamics is a priority issue among equipment manufacturers who participated in Phase 1 outreach. The team plans to incorporate the following next steps.

3.1.3.1 Construct a hybrid test chamber to mitigate the impact of laboratory system control dynamics

While the lab system control dynamics presented in Table 5 will be investigated in full, the research team will construct a calorimetric room inside the psychrometric test chamber during the investigative testing phase in order to accurately account for the impact of the laboratory's thermodynamic influence on test results. This will mitigate concerns that results are influenced by heat transfer to or from the test chamber, while also ensuring accurate measurement of injected loads for non-ducted units.

3.1.3.2 Use best practice from innovative test methods to minimize bias & offset

Innovative test methods incorporate means of accounting for variations in laboratory thermostat controls and manufacturer sensors/controllers. The team has identified this as a best practice that should be carried forward to future test procedure guidance.

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[2] 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

In addition, the team will fully instrument all test setups during investigative testing to determine any additional inputs where bias and/or offset from manufacturer controls impacts the test outcome.

3.2 Equipment Setup Issues

Equipment setup issues are those that deal with how the equipment is setup for testing in the lab. Equipment setup may vary between test units and will impact laboratory testing outcomes. Key equipment setup issues the team identified include thermostat influence, test unit control settings, assembly testing, and adaptive learning algorithms.

3.2.1 Thermostat Influence

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.

In a typical equipment setup, a manufacturer-supplied thermostat or controller is used to control the AC or HP unit during testing. During outreach, the research team explored whether test setups should consider third-party or "smart" thermostats for AC or HP control during testing. Outreach participants showed preference for only testing manufacturer controllers, noting that "smart" thermostats would bring many additional variables to rating equipment performance. This is consistent with current innovative testing methods.

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

The team notes that there is a body of research in progress at Purdue Labs that deals with best practices for thermostat placement, which will be reviewed for applicability once published.

3.2.2 Test Unit Control Settings

The test unit control settings define how the unit under test is setup and programmed to operate during testing. Current and innovative test methods vary in this area, with guidance ranging between standards. Table 6 includes a summary of current practices for test unit control settings.

Table 6: Summary of Test Unit Control Settings

Test Unit Control Settings	Configuration Options	Notes & Considerations
General Operation	• Default Settings • As-Shipped Setting • Per Manufacturer Installation Instructions	• Default/As-shipped may differ significantly from manufacturer instructions • "As-shipped" currently referenced by CSA EXP07
Operating Mode Setting	• Cooling • Heating • Auto	• No innovative test methods account for user-selectable settings, such as "comfort", "Eco", "Tropical", etc.
Airflow Control Setting	• High/Med/Low • Auto • Fan on	• "As-shipped" currently referenced by CSA EXP07. • Intent is to rate operating mode to be used during install • Fan airflow often defaults to "off", which leads to lab judgement
Dip-switch & Remote Settings	• Comfort • Energy Saving / Eco • Tropical / Dehumidify • Etc.	• Significantly impact operation and energy performance

Feedback from polled manufacturers indicated a preference for including multiple operating modes and settings, dependent on the applicable test point or climate region.

The research team's takeaway is that a detailed hierarchy must be developed to guide test labs to which operating modes should be used during testing. This will allow testing using multiple operating modes while reducing the need for laboratory judgement, which can lead to results that are not reproducible or repeatable.

3.2.3 Testing Separate Assemblies

As a potentially new equipment setup approach, the research team posed the possibility of testing separate assemblies during outreach. This entails separately rating the outdoor unit, the indoor unit, and the controller. Individual components are then assigned an overall system performance based on component level performance. The benefits to this approach include eliminating the interplay between the three components, standardizing refrigeration conditions, and the ability to include the impact of third-party and smart thermostats in the system-level performance. Drawbacks to testing separate assemblies include not seeing the influence of control feedback and control algorithms without inclusion of a separate challenge test on the combined system.

Both outreach groups voiced overwhelming preference to maintain the current approach of testing the AC or HP system as a whole rather than testing separate assemblies. This approach will not be pursued during the investigative testing phase.

3.2.4 Adaptive Learning Algorithms

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 outreach participants for feedback on specifics of these adaptive controls but received little or no input. As a result, the investigative testing phase will include observations about how these algorithms affect testing, including:

- How common is it that manufacturers specify a “learning” period?
- How long is a typical “learning” period?
- What are best practices to expedite learning?
- What are best practices to achieve learning while minimizing additional time for setup and testing?

The research team has incorporated these questions into the detailed Phase 2 Investigative Test Plan, which is included as Appendix 2.

3.2.5 Equipment Setup Next Steps

Outreach participants weighed in on which portions of equipment setup issues the research team should prioritize during investigative testing, with the following next steps.

3.2.5.1 Prioritize investigation of thermostat influence through instrumentation.

Fully instrument all test setups during investigative testing to investigate the impact of thermostat location and identify methods for testing units with more than one return air input. Third-party thermostats will not be included in the Phase 2 investigation.

3.2.5.2 Include multiple modes of operation in the investigative testing matrix.

Outreach participants indicated that multiple operation modes should be considered for different climate conditions in the developed test methodology. The research team will include investigation into available operation modes, as well as testing in various operating modes in the Phase 2 Investigative Test Plan.

3.2.5.3 Do not pursue testing separate assemblies

While the research team sees benefits to approaching testing from a component-based approach, feedback from outreach participants indicates a lack of support for this path. This will not be included in the Phase 2 Investigative Test Plan.

3.2.5.4 Continue to investigate accounting for adaptive learning algorithms

The research team received little to no input regarding best practices for incorporating adaptive learning periods into the test methodology. Therefore, investigative testing will include observation to identify typical adaptive learning periods and how to account for these during testing.

3.3 Test Approach Issues

The test approach deals with the method of testing the AC or HP unit. Key issues identified in this category include which load-based testing concept to incorporate, whether to include calorimetric or air-enthalpy test methods, and the burden incurred from the chosen approach. These issues are less impacted by investigative laboratory testing but did require discussion during the outreach portion of the investigation.

3.3.1 Load-based Testing Concept

During review of innovative test methods, the team observed that the current load-based tests use two distinct testing concepts. These include a dynamic load response and a target compensation load. These two concepts are further described in Table 7.

Table 7: Test Concept Comparison

Test Concept	Description	Innovative Test Method Use
Dynamic load response	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 EXP07 • 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 EXP07 • EN 14511 with BAM/RiSE load-based testing modification

There was significant discussion of this issue during the outreach forums. The group agreed on the following:

- A dynamic load response test is appropriate to observe and validate controls behavior and component operational ranges, but less favorable in measuring heating and cooling load performance results due to the difficulty in repeatability/reproducibility of test results. How a load response is achieved impacts the unit performance, and therefore the measured efficiency at any given operating point.

- A target compensation load test provides some benefit of native control since compressor speeds are not locked during testing. Performance results are likely to be more repeatable/reproducible than those measured in a dynamic load test due to the balanced condition during measurement. The drawback is that the more controlled nature of the test conditions may demonstrate less of a real-world controls response.

Polling results of outreach participants indicated a group preference for the target compensation load test concept. While the team will continue to observe the benefits and drawbacks of these two testing concepts during the investigative testing phase, the current intent is to move forward with a target compensation test concept.

Outreach to test labs employing load-based testing techniques indicated that identifying a consistent method to approach test conditions is an important consideration that is not fully identified in current innovative test methods. Lab observations show that testing results are impacted by both how quickly and from what direction the test point is achieved. This applies to both target compensation and dynamic test concepts, but more specifically to testing using the air-enthalpy test method. Techniques for achieving test conditions will be further investigated during Phase 2 testing.

3.3.2 Calorimetric vs Air-Enthalpy Test Method

The calorimetric room test method measures the energy input to the equipment serving a known load injected into the conditioned room, as opposed to measuring air inlet and outlet conditions directly. This method is more accurate for non-ducted systems and is typically used to test and rate ACs and HPs with capacities less than 3.5 Tons (12 kW).

The air-enthalpy test method measures air inlet and outlet conditions directly at the indoor fan coil unit. While available internationally, this method is most used in the U.S. due to the prevalence of ducted AC and HP systems. It can be used to test systems larger than 3.5 Tons (12 kW). Simple schematics of both test methods are shown in Appendix 2 for reference.

Current international AC and HP test procedures include both calorimetric and air-enthalpy test methods for testing and rating equipment. Innovative test methods break from this standard, with the EN 14511 BAM/RiSE load-based test method currently including only a method for testing via the room calorimetry approach and the CSA EXP07 only offering a procedure for air-enthalpy testing.

The research team polled outreach participants on which test method(s) should be included in the load-based test guidance. Response overwhelmingly supported including both calorimetric and air-enthalpy test methods in the guidance.

The research team will proceed with including both test methods in the test guidance. The Phase 2 Investigative Test Plan includes testing to attempt to quantify and compare results from these two test methods to further guide next steps regarding included test methods.

3.3.3 Test Burden

Manufacturers voiced the concern of test burden as a barrier to acceptance of load-based testing. While outreach participants indicated that there are both manufacturer and research labs that are equipped to perform load-based testing, the research team anticipates that the time needed to characterize system performance using load-based testing is likely to be higher than that of fixed-speed test methods.

Feedback from those familiar with CSA EXP07 testing noted the following observations regarding time required for characterizing system performance:

- Manufacturer controls vary, and in some cases, time is required just to observe the behavior of the unit under test to assess the required next action.
- Time to test increases when test conditions must be reset between each test condition.

The research team would like to further understand the following as part of the investigative test phase:

- What are the additional facility requirements and/or tuning strategies required between testing units of varying capacity ranges, and how do these impact the total test time and burden?

3.3.4 Performance Mapping Approach

Discussion with the manufacturer outreach participants included the use of performance mapping to generate climate-specific performance for any installation location or condition. The research team pursued this idea with a follow-up discussion with the National Renewable Energy Laboratory (NREL). The team found that, while NREL had some unique ideas on the interaction between lab and unit control systems, no major advancements have been made regarding system performance mapping for ACs and HPs.

In the U.S., manufacturers currently have the option to rate performance through Alternative Efficiency Determination Methods (AEDMs), which rates equipment based on compressor performance maps and validated software calculations, as was suggested during outreach.[3] If desired, other regions could consider adopting similar approaches for variable capacity or fixed speed units. The research team considers this issue resolved, without requiring further investigative testing.

3.3.5 Test Approach Next Steps

The research team will proceed with the following next steps with respect to the test approach.

[3] AEDMs are described in more detail in US DOE CFR 431.174. Current version can be found here: https://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol3/pdf/CFR-2011-title10-vol3-sec431-174.pdf

3.3.5.1 Proceed with a target compensation load testing concept

Quickly changing testing conditions during load-based testing of variable capacity ACs and HPs leads to a lack of clarity in real time as to whether the lab control or unit control is impacting the results. The rate and method of test point approach are important factors in achieving repeatable/reproducible lab test results. This, combined with feedback from outreach forums, leads the team to conclude that a compensation load concept is the best path for developing the load-based testing methodology. The research team concludes that a dynamic testing approach is appropriate for a controls verification protocol, should that be necessary to add during test methodology development. The method of test point approach will continue to be investigated during Phase 2 investigative testing.

3.3.5.2 Include both calorimetric and air-enthalpy test methods in the test methodology

The research team found that existing innovative test methods currently include either calorimetric or air-enthalpy test methods, but not both. Outreach participants overwhelmingly agreed that both calorimetric and air-enthalpy test methods should be included in the developed test methodology.

3.3.5.3 Identify and incorporate opportunities to streamline lab testing to reduce burden

Manufacturer outreach participants indicated that test burden is a concern in the adoption of changing test procedures. While no specific practices were identified to reduce burden, the research team acknowledges that a clear test procedure that requires minimal laboratory judgement will alleviate the burden of transitioning to a new test procedure.

3.3.5.4 Do not include a system performance mapping approach in the Phase 2 Investigative Test Plan

The research team concludes that this is a policy-based capability that is already available to AC and HP manufacturers and is necessary to include in a load-based test methodology.

3.4 Impact of Climate Region on Results

Past investigation into international AC test methods showed that climate bins set at the jurisdictional level have a larger impact on performance ratings than do the actual test conditions. During outreach, manufacturer feedback indicated there is more interest in pursuing regional climate-specific ratings than an internationally standard rating approach.

Since regional climates cannot be addressed in an international test procedure, the research team will focus on the test methodology (e.g., how to setup and test AC and HP units) at this time, with less emphasis on gaining consensus on specific test conditions. Representativeness of performance metrics is achieved by properly defining climate bin temperatures for seasonal energy consumption calculations, so the topic of regionally specific performance must be revisited by local jurisdictions in the future.

Section 4 Conclusions

After initial development of a solid understanding on the identified key issues, the research team established collaborative communication with many parties familiar with load-based testing considerations. The team incorporated valuable feedback into the key issues and approach to investigative testing. The final position on the identified key issues is summarized in section 4.1, followed by a summary of the Phase 2 Investigative Test Plan in section 4.2.

4.1 Updates to Key Issues

As noted in Section 3, the team began with a list of identified key issues to investigate. Following investigation and outreach to interested parties, the team has made the following refinements to the list of key issues.

Table 8: Findings Impact on Phase 2 Investigative Testing

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

Key Issues	Impact to Investigative Test Plan
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
• 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

After compiling the above findings, the team developed a detailed plan for the investigative testing to be completed during Phase 2 of the project. A summary of the Investigative Test Plan is shared in section 4.2.

4.2 Phase 2 Investigative Test Plan Summary

Phase 2 investigative testing will evaluate the performance of three variable capacity air-source HPs. The research team selected 2 non-ducted systems and 1 ducted system at a range of capacities to allow evaluation of how various configurations impact test performance. The planned test units are shown in Table 9.

Table 9: Phase 2 Investigative Test Units

Test Unit	Nominal Capacity	Configuration	AC or HP
1	15,000 Btu/h	Non-Ducted	HP
2	24,000 Btu/h	Non-Ducted	HP
3	36,000 Btu/h	Ducted	HP

Table 10: Phase 2 Investigative Test Table 10 provides a summary of test configurations included in the Investigative Test Plan. These test configurations were chosen to address the refined key issues outlined in Section 4.1 above. In particular, the test configurations will evaluate the impact of lab system control dynamics, input control bias/offset, test unit control setting, and thermostat influence on test results. Research questions focused on adaptive learning algorithms and test burden rely more on general observations during testing rather than on specific test configuration. A more detailed Investigative Test Plan is included in Appendix 2.

Table 10: Phase 2 Investigative Test Summary

Test Name	Description
Method Validation[2]	Box Calibration
Energy Balance[2,3]	Indoor Room Calorimeter/Outdoor Air Enthalpy
Energy Balance[3,4]	Indoor Air Enthalpy/Refrigerant Enthalpy
Control Observation[2,4]	Input bias/offset determination and facility response tuning
Simulated Use[2]	Factory Default Cooling Day/Factory Default Heating Day
Simulated Use[2]	Efficiency Optimized Cooling Day/Efficiency Optimized Heating Day
Control Validation[4]	AHRI 1230 CVP at Full, Intermediate and Minimum Cooling
Compensation Load[2,4]	Factory Default Cooling/Factory Default Heating
Compensation Load[2,4]	Efficiency Optimized Cooling/Efficiency Optimized Heating
Sub-Minimum Load[4]	Forced Cyclic Cooling

The Phase 2 investigative testing will be carried out in coming months. A report on finding from investigative testing is scheduled to be completed in May 2021. Development of the load-based test methodology and round robin test plan will follow.

[2] Applies to non-ducted units tested using the calibrated box
[3] Evaluate in cooling (full) and heating (full) modes
[4] Applies to ducted units with the metering device in the indoor unit

Appendix 1: List of Consultees

The following consultees were contacted for feedback during this research.

Name	Organization	Email Address
IEA/4E Members		
Mark Ellis	IEA 4E TCP	mark@energyellis.com
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Research Outreach Participants / Respondents		
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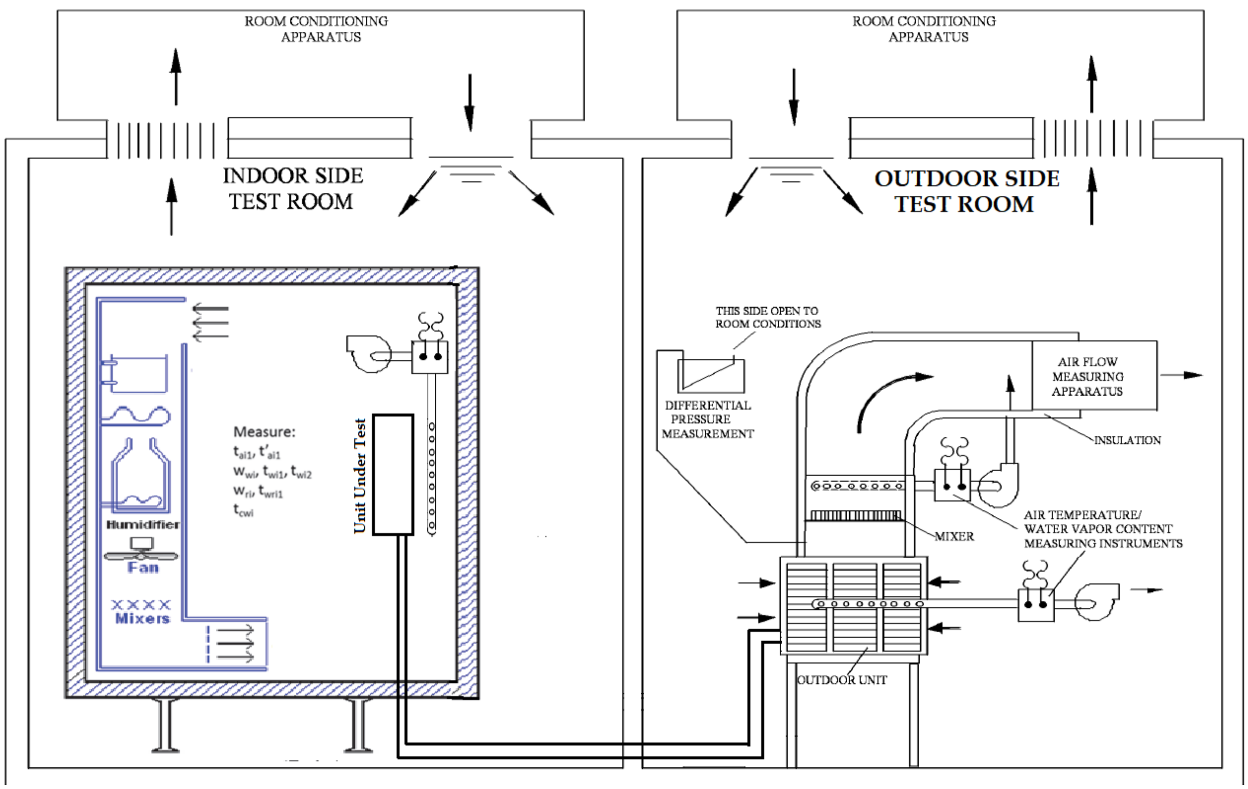
Pilar Garcia	CEIS, Spain	

Appendix 2: Phase 2 Investigative Test Plan

Non-ducted Systems

The investigative testing of non-ducted systems will utilize a hybrid of two existing, well-defined test methods. The test facility is a modified psychrometric room that includes a calibrated box on the indoor side and will employ an outdoor air measurement apparatus to allow for an energy balance confirmation at full load in both cooling and heating modes.

Figure 1: Calibrated Box/Outdoor Air Enthalpy Method (Hybrid Method)



Non-ducted HP systems will undergo the following investigative testing.

Table 11: Non-Ducted System Investigative Test Sequence

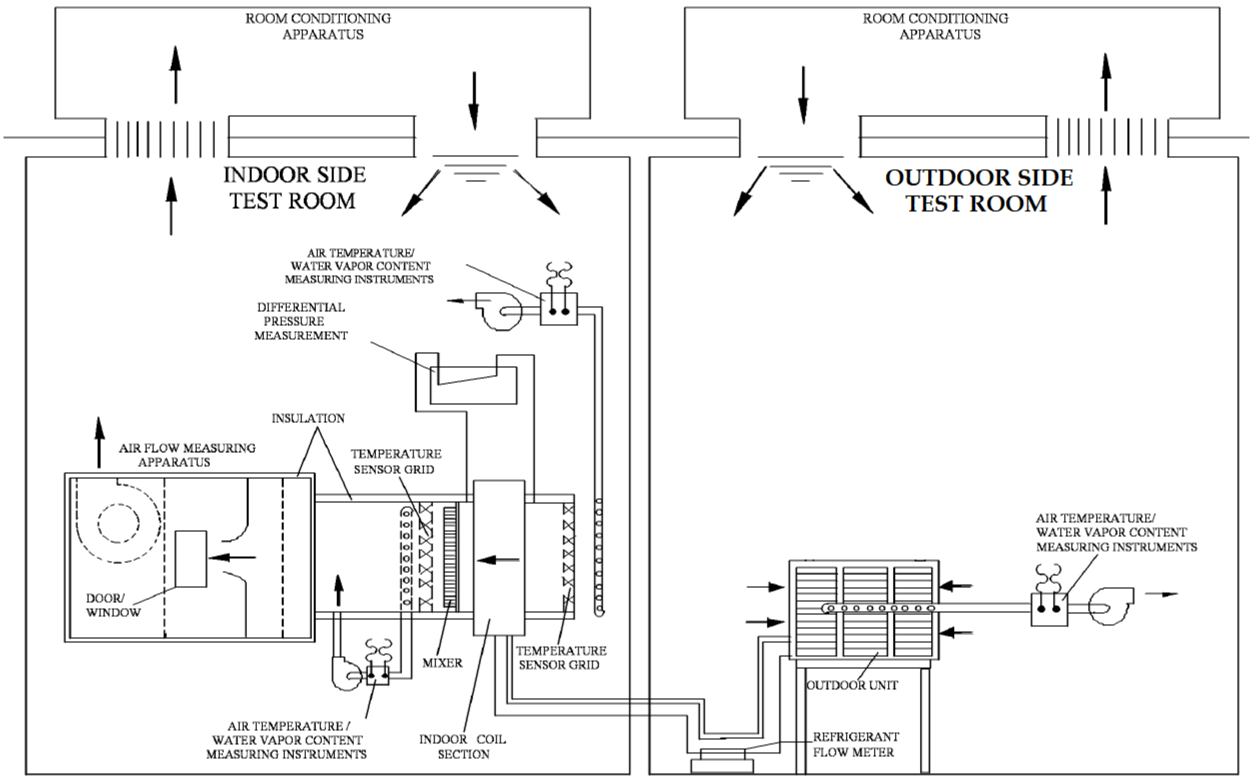
Test #	Test Name	Description	Method
1	Calibration	Box Calibration per ASHRAE 16 (25F)	Box Calibration
2	Balance 1	Sensible only maximum Cooling	Indoor Room Calorimeter/Outdoor Air Enthalpy
3	Balance 2	Sensible and latent Cooling	Indoor Room Calorimeter/Outdoor Air Enthalpy

Test #	Test Name	Description	Method
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
	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 System

The ducted system will be evaluated in a standard psychrometric facility with modified parameters to allow for manual control of sensible and latent loads. Refrigerant enthalpy method shall be used provided the metering device is located in the indoor section. Alternatively, the outdoor air enthalpy method shall be used to confirm energy balance at full load cooling and heating operation.

Figure 2: Indoor Air Enthalpy/Refrigerant Enthalpy Method



Source: ASHRAE 37-2009 (Figure 1)

Ducted HP systems will undergo the following investigative testing.

Table 12: 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

Test #	Test Name	Description	Method
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
	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

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

Appendix 3: Outlined Test Method Approach

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)

Configuration	Heat Rejection	Indoor Arrangement	
Single Package System	Air Cooled	Blower Coil	Ducted
			Non-ducted
	Air Source		Ducted
			Non-ducted
	Liquid Cooled		Ducted
			Non-ducted
	Liquid Source		Ducted
			Non-ducted
	Evaporatively Cooled		Ducted
			Non-ducted
Single Split System	Air Cooled	Coil Only	Ducted
		Blower Coil	Ducted
			Non-ducted
	Air Source	Coil Only	Ducted
		Blower Coil	Ducted
			Non-ducted
	Liquid Cooled	Coil Only	Ducted
		Blower Coil	Ducted
			Non-ducted
	Liquid Source	Coil Only	Ducted
		Blower Coil	Ducted
			Non-ducted
	Evaporatively cooled	Coil Only	Ducted
		Blower Coil	Ducted
			Non-ducted

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