CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Residential Refrigerant Charge Testing and Related Issues

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team December 2011

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1. Purpose

1.1 Introduction:

The California Investor Owned Utilities (IOUs) are actively supporting the California Energy Commission (CEC) in developing the state's building energy efficiency standard (Title 24) through their Codes and Standards (C&S) program. The joint intent of the IOUs and CEC is to achieve significant energy savings through the development of reasonable, responsible, and cost-effective code change proposals for the 2011 code update.

Through Codes and Standards Enhancement (CASE) Studies, the IOU C&S Program provides standards and code-setting bodies with the technical and cost-effectiveness information required to make informed judgments on proposed regulations for promising energy efficiency design practices and technologies.

This CASE study focuses on measuring refrigerant charge and proper operation of residential air conditioning systems. It includes a new protocol designed to work under various outdoor and indoor temperature conditions that will allow verification testing during the winter months, something that is not possible using the current method specified in RA3.2 and 3.3 of the 2008 Residential Appendices.

The outcome of this study and subsequent actions by the California Energy Commission should improve compliance with air conditioner installation standards.

Work on this CASE study was funded by the IOU C&S program, and work was conducted by Bruce Wilcox, P.E. and Proctor Engineering Group, Ltd.

1.2 Problem Statement:

Most residential air conditioners undergo final assembly at the location of their installation, far from the production line and manufacturing quality control. As a result many of the new air conditioners in California fail to achieve their rated efficiency due to improper amounts of refrigerant, improper evacuation, metering device malfunctions, and other problems. To address this situation, the California Building Energy Efficiency Standards define methods of verifying correct charge and proper air conditioner system operation. These methods were developed from the major manufacturers' specifications and verification protocols and outlined in the 2008 Title 24 part 6 (2008 Title 24 henceforth) Reference Residential Appendix RA 3.2.2.

These requirements caused significant problems for HERS raters and contractors as the 2008 Title 24 Standards were implemented in early 2010. Implementing these methods on a statewide basis has revealed a number of shortcomings of these methods.

- There was no winter HERS verification protocol to obtain a certificate of occupancy or closing a permit[1].
- Most manufacturers specify a single target subcooling for setting the amount of refrigerant, regardless of the test conditions. This is problematic because, with a fixed amount of refrigerant, the actual subcooling varies with differing indoor and outdoor conditions. As a result the contractor might set the refrigerant to meet the standard under one set of conditions, but the HERS rater might test and fail the unit under a different set of conditions.
- Air conditioners with microchannel condenser coils (which contain very little refrigerant) have been introduced into the market. These units produce even larger variations in subcooling as conditions change.
- The temperature split method is used as a qualifier for refrigerant charge testing. The temperature split method provides a rough indication of airflow but it is subject to both false positives (airflow OK) and false negatives (airflow not OK). It can give different answers for the same unit when nothing is changed except the operating conditions.

In addition to addressing questions raised during the implementation of the 2008 Title 24 Standards, this CASE study addresses a couple of additional issues:

- On occasions where the installation technician fails to evacuate the system properly, there will be air (non-condensables) mixed with the refrigerant. This mix will cause mischarge of the unit and reduced efficiency.
- Shortcomings in the current national SEER test and rating procedure.

On the positive side, the implementation of the SEER 13 National Standard has resulted in the use of thermal expansion valves (TXVs) in virtually all new residential air conditioners. This makes some simplification possible.

This study also provided the opportunity for manufacturers to test their Charge Indicator Displays in a laboratory setting.

1 Local building departments could provide conditional approval.

2. Overview

a. Measure Title	Refrigerant Charge Testing Protocols for Residential HVAC Systems
b. Description	This CASE topic proposes changes to the methods of verifying correct charge and proper air conditioner system operation for residential split systems for space cooling. These changes allow additional procedures to conduct testing under low outside air temperatures, they modify criteria for testing with the subcooling method, they eliminate the temperature split qualification method, and they propose a new charge method for systems with microchannel condenser coils.
c. Type of Change	**Prescriptive Requirement -** The change would add additional methods of verifying compliance with the existing prescriptive refrigerant charge requirement. **Modeling** - The change would not modify the calculation procedures or assumptions used in making performance calculations. **Documents –** The following documents are affected: 1. Residential Appendix RA3 2. Joint Appendix J6 3. Residential ACM Approval Manual 4. Residential CF-4R and CF-6R
d. Energy Benefits	There is no change in the energy benefits relative to the 2008 Standards aside from potential improved compliance.
e. Non-Energy Benefits	These changes can produce a higher level of compliance with the Refrigerant Charge Testing Requirement and lower the cost of verification.
f. Environmental Impact	The measure has no adverse environmental impact.
g. Technology Measures	**Measure Availability:** All materials required for the proposed changes to the reference appendices already exist. **Useful Life, Persistence, and Maintenance:** No change is being proposed to the useful life, persistence or maintenance of affected systems.

h. Performance Verification of the Proposed Measure	The proposed methods are improvements over the existing testing protocols in the 2008 Title 24 standards. They allow refrigerant charge testing over a larger set of environmental conditions and are less likely to produce false failures.
i. Cost Effectiveness	This will improve cost effectiveness by eliminating the wait time between AC installation and HERS verification for some units.
j. Analysis Tools	No new analysis tools are needed.
k. Relationship to Other Measures	The Airflow and Fan Watt Draw measure becoming mandatory simplifies the Refrigerant Charge Testing Protocol by making the temperature split method unnecessary.

3. Methodology

3.1 Scope of Work:

The work consisted of a series of laboratory tests on two typical split system air conditioners to test protocols and provide performance data under a range of refrigerant charge and environmental conditions. The test conditions included undercharge and overcharge, as well as outdoor temperatures from cold (37°F) to hot (95°F) all in the cooling mode.

The work also included a review of the temperature split method.

The following items were investigated under this CASE study:

- Testing a potential winter charge testing procedure utilizing a restriction in the outflow from the condenser fan.
- Adjusting the limits of acceptability for subcooling for the HVAC installer and the HERS rater based on the change in efficiency outcomes. Providing achievable methods of setting refrigerant charge on air conditioners with small refrigerant passages.
- Testing the efficiency effect of improper evacuation and non-condensables in the refrigerant.
- Improving the test method that rates the cycling efficiency of units, particularly in California's dry climates.
- Testing the response of Charge Indicator Devices (CIDs) to various conditions of refrigerant charge, airflow, and climate conditions.

Details of the conditions of the tests are listed in 7.1 Appendix A: Intertek Testing Conditions.

3.2 Description of Laboratory Tests

3.2.1 Equipment

The tested air conditioners were nominal 2.5 ton SEER 14 units with TXVs and R-410A refrigerant.

The outdoor unit consisted of the condenser, compressor and condenser fan. The indoor units were common evaporator coils enclosed in ductwork and supplied with the appropriate Thermostatic Expansion Valves (TXV).

This equipment is of current manufacture. The units were installed with a 50 foot lineset to simulate typical installations.

3.2.2 Test Facility

These tests were performed at the Intertek psychrometric rooms in Plano, Texas. This facility is regularly used by the manufacturers to certify their units to AHRI. The facility consists of a climate controlled indoor room and a climate controlled outdoor room. The facility has the ability to cover a wide range of climate conditions from very hot summer conditions to very cold winter conditions.

The air conditioner was installed in the test rooms by the technicians of Intertek. All brazing was accomplished with a nitrogen bath and proper evacuation procedures were followed.

The Intertek technicians equipped the air conditioner with their standard test instruments. A of the testing instrumentation is shown in

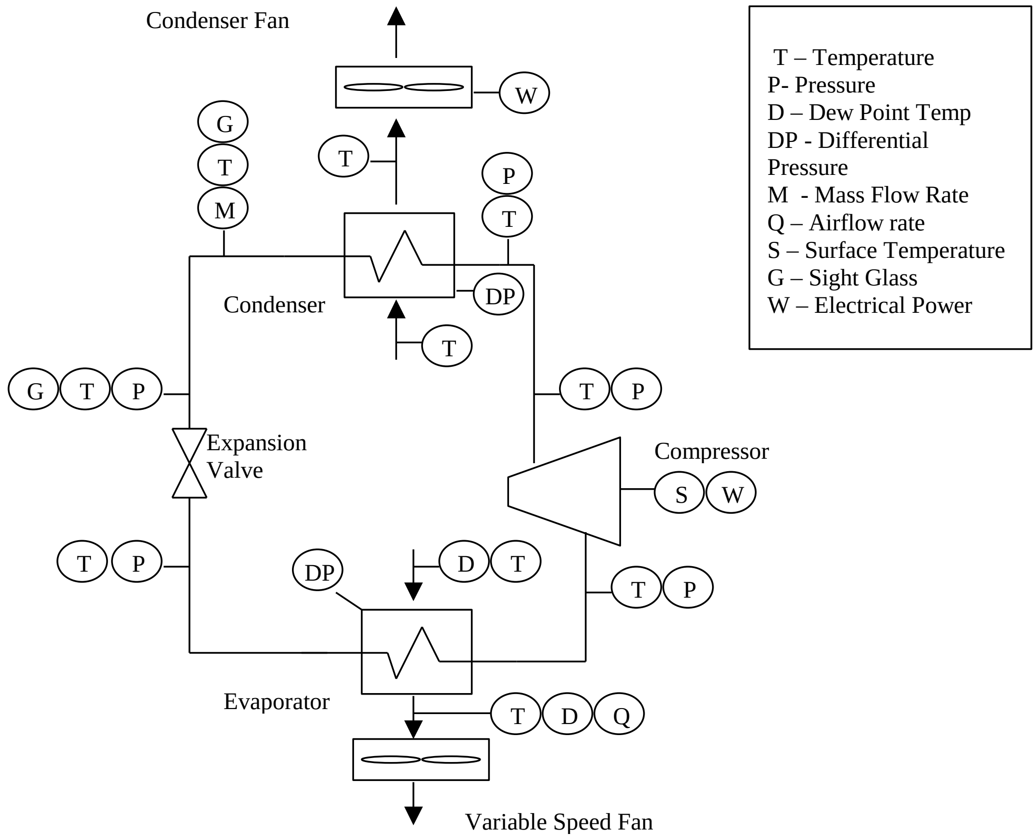


Figure 1.

3.2.3 Performance Measures

The instrumented facility provided data to produce the following common performance metrics:

- Sensible Capacity – the amount of cooling as temperature reduction in BTU/hr.
- Latent Capacity – the amount of cooling as dehumidification in BTU/hr.
- Total Capacity – the total cooling including both sensible and latent capacity
- Sensible EER – The sensible capacity divided by the watt draw
- Total EER – The total capacity divided by the watt draw

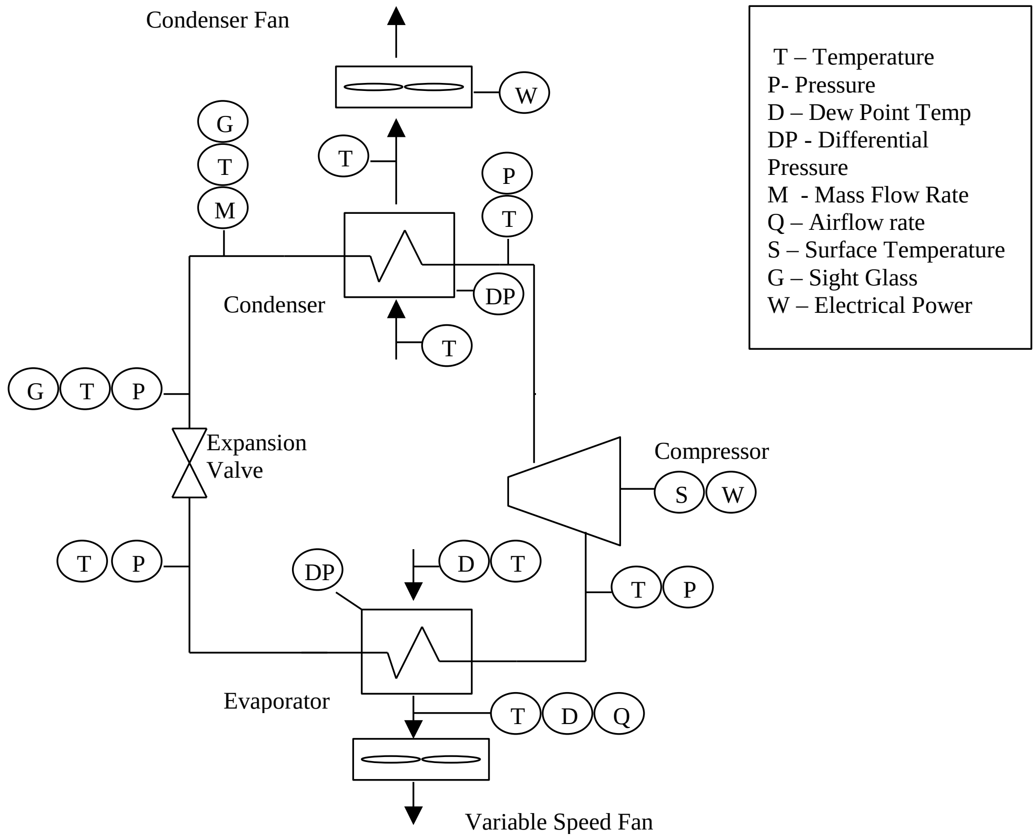


Figure 1. Testing Equipment Schematic

3.3 Test Descriptions

Two types of tests were conducted - Steady State and Cycling.

The Steady State tests consisted of running the air conditioner and adjusting the rooms' conditions until all the parameters were maintained within the limits set for certification testing. Once steady state was achieved, the parameters were recorded for 20 minutes. The test summaries in 7.2 Appendix B: Steady State Test Summaries present the parameter averages over the 20 minute test period.

The Cycling tests consisted of adjusting the rooms' conditions until all the parameters were maintained within the limits set for certification testing. Once the conditions were stabilized, the parameters were continuously recorded for the duration of the tests. The cycles alternated 6 minutes of compressor running with 24 minutes of the compressor off. This test sequence is the sequence used in the SEER cycling test also known as "DOE Test D"[2].

The test summaries in 7.3 Appendix C: Cycling Test Summaries present the maximum cumulative performance over the test cycle as well as the average test rooms' conditions.

3.4 Temperature Split Investigation

The temperature split method is a qualitative airflow indicator that fits easily into technicians' standard diagnostic tests. Temperature split is the difference between the supply plenum dry bulb temperature and the return plenum dry bulb temperature. This temperature difference is a strong indicator of the correct operation of the air conditioner. For any given set of conditions (return plenum wet and dry bulb temperature and outside coil inlet temperature), there is an expected temperature split for a proper operating unit. The expected temperature split is the "Target Split". A measured temperature split within 3°F of the Target Split is considered acceptable. A measured temperature split outside that range is a strong indication that there is a problem with the machine. When the temperature split is too large it is an indication of low airflow through the inside coil. When the temperature split is too low it usually indicates low cooling capacity which can be associated with a number of problems including: improper refrigerant charge, dirty outside coil, low airflow through the outside coil, compressor problems, contaminated refrigerant, restrictions in lines, orifice problems, and others.

Temperature split is an imprecise tool because it is the interaction between the airflow, the cooling capacity of the unit and the indoor and outdoor conditions. The most common version of the method is used by Carrier Corporation and other manufacturers (Carrier 1994). That version only takes into account the return wet bulb and dry bulb temperature and has been found to give biased results with respect to return wet bulb temperature (Downey & Proctor 2002).

2 AHRI Standard 210/240

The Carrier version also does not account for differences in the outdoor temperature and suggested changes have been made for improving its accuracy (Downey & Proctor 2002; Temple 2008; Mowris 2010). At this point there is no consensus on any revised version of the temperature split method.

It is common for the personnel not familiar with the pitfalls of the temperature split method to misinterpret the results of the test. There have been suggestions that other methods be used whenever practical and possible ([CEC 2001]; Downey & Proctor 2002; Metoyer, Swan, & McWilliams 2009).

The proposals for the 2013 Standards include making measured airflow a mandatory measure. When this is accomplished, there will no longer be a need to use the temperature split method.

4. Analysis and Results

4.1 Summary Findings

- The current acceptance limits for HERS verification are too narrow to avoid false failures at the time of the HERS verification test. New limits are proposed based on an acceptable range of efficiency variation.
- Air conditioner refrigerant charge can be successfully adjusted using a low temperature protocol. The proposed protocol achieves Sensible EERs that are within 2% of the Sensible EERs using the summer charge test protocol.
- Charging to a target liquid line temperature is a valid method of obtaining correct and uniform refrigerant charge levels and produces superior charging results on low volume coils. The method should be an accepted alternative.
- Improper evacuation leaves non-condensables mixed with the refrigerant. Even a mild amount of non-condensables produce a 7.5% reduction in Sensible EER.
- Commonly used certification laboratories can run valid cycling test at conditions more representative than the current SEER cycling test. When the improved test method is used it points to potential savings in hot climates of up to 41%.
- Charge Indicator Displays (CIDs) show promise in providing constant monitoring of air conditioners. The laboratory tests showed that two manufacturers are close to producing units that can meet the Title 24 specifications.

The full texts of these conclusions are contained in Section 4.4 Conclusions of this report.

4.2 CASE Recommendations

Based on the laboratory testing as well as review of manufacturer's data, available field data, and existing studies, the following changes are recommended:

- Approve the Condenser Outlet Air Restriction Winter Testing protocol for both contractors and HERS verifiers.
- Widen the subcooling acceptance limit for HERS verification of TXV system subcooling to;
  - Greater than 2°F and
  - Within ±6°F of the manufacturer's specified subcooling target.
- Approve liquid line temperature method for units that the manufacturer specifies the liquid line temperature method for setting charge. This method is necessary for units with small refrigerant channels such as micro-channel heat exchangers.
- Eliminate the temperature split method if direct airflow measurement becomes mandatory.
- Investigate the prevalence of non-condensables and other faults in residential split air conditioners to determine the available savings.

- Support revisions to the SEER rating including upgrading the cycling test to a more representative 95°F outside temperature with indoor conditions of 80°F with 50% relative humidity (67°F wet bulb).
- Continue to encourage the development and manufacture of Charge Indicator Displays meeting the specifications of the 2008 Standard.

Detailed revisions to the Residential Field Verification and Diagnostic Test Protocols (2008 Title 24 Standards Appendix RA3) are contained in Section 5.

4.3 Detailed CASE Findings

In this section we provide an overview of the results of the laboratory tests described above as well as a discussion of how they compare with results/data from other sources. Findings are presented individually for each of the specific areas outlined in the 'Scope of Work' section of this document.

4.3.1 Achieving Equivalent Efficiency while Charging at Low Outdoor Temperatures

In order to provide a method for verifying refrigerant charge at low temperatures, it is first important to identify the goal of the verification. Given that Title 24 is an energy efficiency building standard, the appropriate goal is achieving efficiency.

This study investigated a possible low outdoor temperature refrigerant charge protocol. Virtually all the air conditioners sold in California today have Thermostatic Expansion Valves (TXVs). A TXV is a constant superheat valve that adjusts its resistance to refrigerant flow to obtain a constant superheat.

The basic problem with low temperature refrigerant charging of TXV air conditioners using current procedures in the 2008 Title 24 is that the valve adjusts to its fully open position. The fully open position occurs when the pressure across the TXV is insufficient to push the required volume of refrigerant through the valve to maintain a stable superheat. This problem exists at low outdoor temperatures when the condenser saturation temperature and pressure are low. By increasing the condenser saturation temperature and pressure, the TXV can function within its design parameters and provide proper refrigerant control. In commercial building air conditioners this is accomplished by slowing down the condenser fan speed (or reducing the number of operating condenser fans).

Various test methods have been attempted to increase condenser pressures and temperatures in cold weather. The two prominent methods are: 1) a tent covering the condenser unit causing recirculation of expelled warm air through the condenser and 2) blocking part of the condenser coil entrance. These two methods have generally proven unsatisfactory. The first causes major alterations in the temperatures entering the coil and the latter produces irregular flow or heat transfer through the refrigerant circuits.

Lennox Corporation currently allows blocking part of the condenser coil entrance to charge some of their TXV models in the winter.

The Condenser Air Exit Restriction (CAER) Protocol overcomes these issues. Restricting the outlet from the condenser fan without disturbing the inlet conditions has proven to be a viable method of low temperature testing. Bringing the pressure drop across the TXV to at least 160 psi for R-410A has the same effect as higher test temperatures. An example of a CAER is shown in Figure 2.

Figure 2. An Example of a Condenser Air Exit Restrictor

The sequence of each proof test at Intertek consisted of:

- Baselining the efficiency of two air conditioners at standard conditions with refrigerant adjusted to the manufacturer's specification.
- Undercharging and Overcharging the units to obtain a 5% loss in Sensible Efficiency
- Lowering the indoor temperature and outdoor temperature to provide severe winter conditions.
- Restricting the outflow from the condenser fan without disturbing the inlet to the coil.
- Recharging (adding or removing refrigerant) to produce the manufacturer's specification with the unit in the cold/restricted condition.
- Bringing the units back to standard conditions and determining the sensible efficiency of the units charged using the CAER protocol.
- Rerunning the unit with baseline charge adjustment for final comparison.

The results of the testing as illustrated in Figure 3 and Figure 4 below and detailed in 7.2 Appendix B: Steady State Test Summaries are used to produce a protocol that limits the sensible efficiency effect of refrigerant charge to substantially less than 5%.

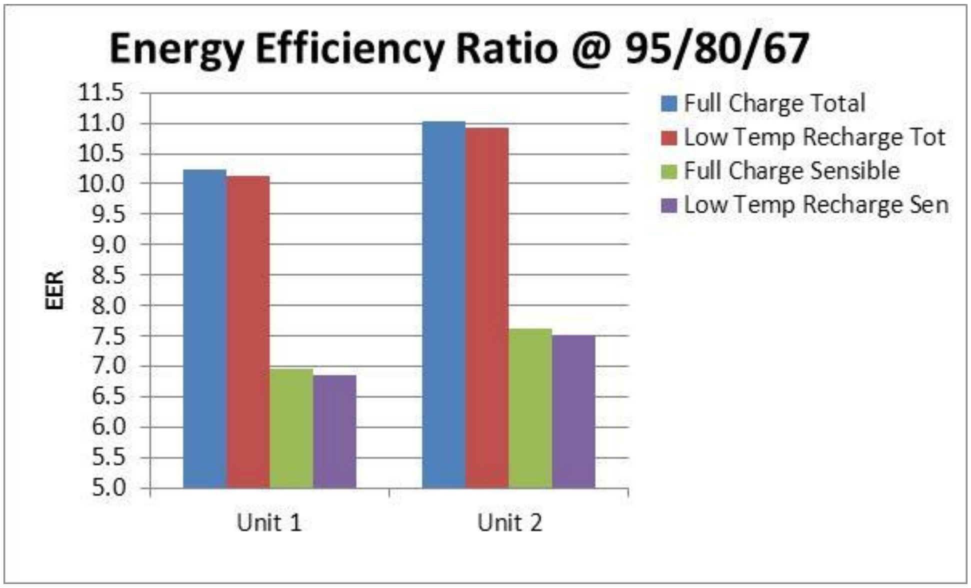
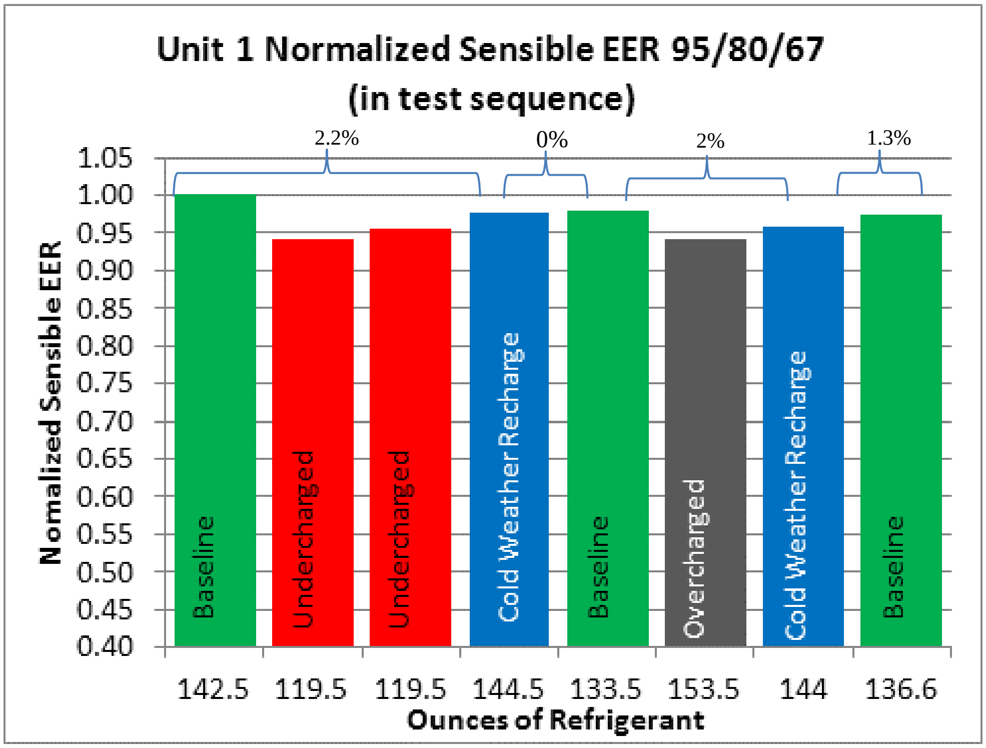


Figure 3: Energy Efficiency Ratio Comparison: Standard and Low Temperature Methods

The efficiency of both units adjusted using the Condenser Air Restriction Protocol (Cold Weather Recharge) was less than 2% different from the average baseline efficiency of those units adjusted with the standard (summer) protocol.



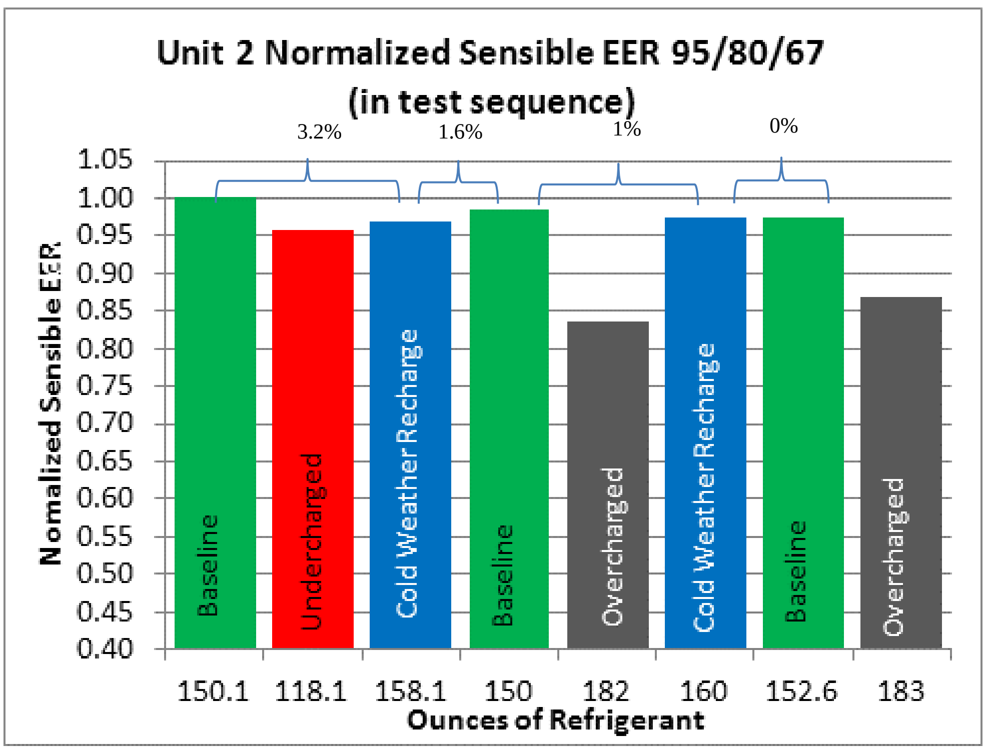


Figure 4: Detailed Energy Efficiency Ratio Comparison: Standard and Low Temperature Methods, Unit 1 and Unit 2.

4.3.2 Subcooling Acceptance Limits

Subcooling in this section is always in degrees Fahrenheit.

The variability of subcooling with outdoor and indoor conditions has been ignored for many years. It has always been present, but the results have generally been considered "good enough" for field adjustment of refrigerant levels. The advent of air conditioners with less refrigerant volume and the need for charging and verification over a range of conditions necessitates taking these variations into account.

This study investigated the possible acceptance limits for subcooling based on the effect the limits would have on the efficiency of the air conditioner.

Subcooling Variability with Identical Refrigerant Charge

Figure 5, courtesy of Trane Corporation, shows the subcooling variation for units charged at 95°F (the upper line of data points) when tested at 82°F (the lower cloud of data points). This variation is partially due to the difference in outdoor temperature and partially due to the differences in indoor conditions and coils (which results in different suction/low side pressures).

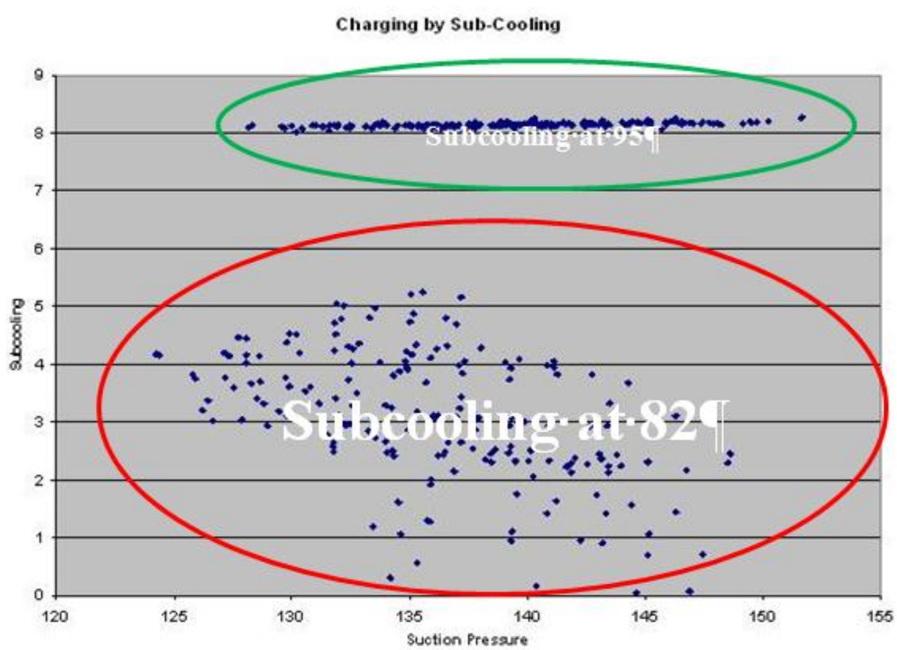


Figure 5: Subcooling Variation with Constant Refrigerant Charge for Microchannel Condenser Air Conditioner

The tests conducted in support of the CASE study also showed variation in subcooling with outdoor temperature. The CASE study tests included two paired comparisons with identical conditions (refrigerant volume, airflow and indoor conditions) where only the outdoor temperature changed. Figure 6 shows three degrees subcooling variation with constant refrigerant charge when the outdoor temperature changes from 82°F to 95°F.

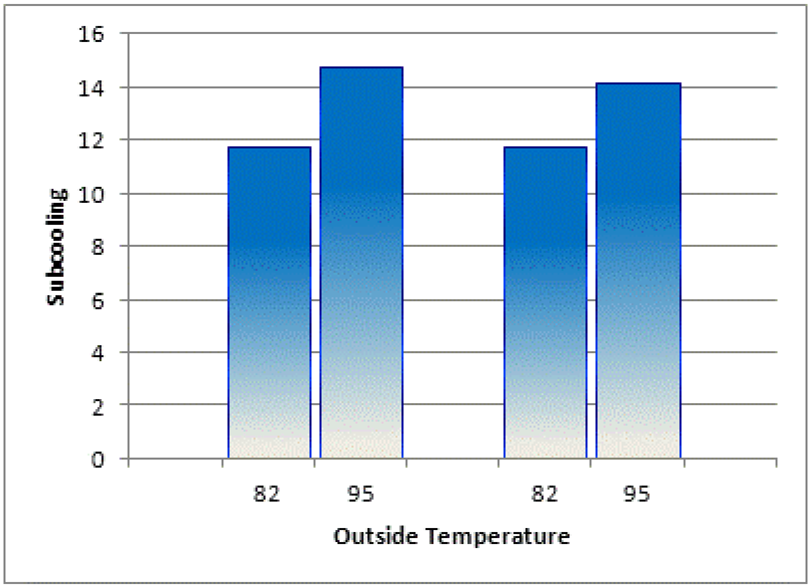


Figure 6: Subcooling Variation with Constant Refrigerant Charge for CASE Study Air Conditioner Tests

Trane ran 1800+ combinations through their simulation model for their conventional XR family of models. The resulting variation from outdoor temperature alone was similar to the lab tests in Figure 3. The plot of these model runs is reproduced in Figure 7.

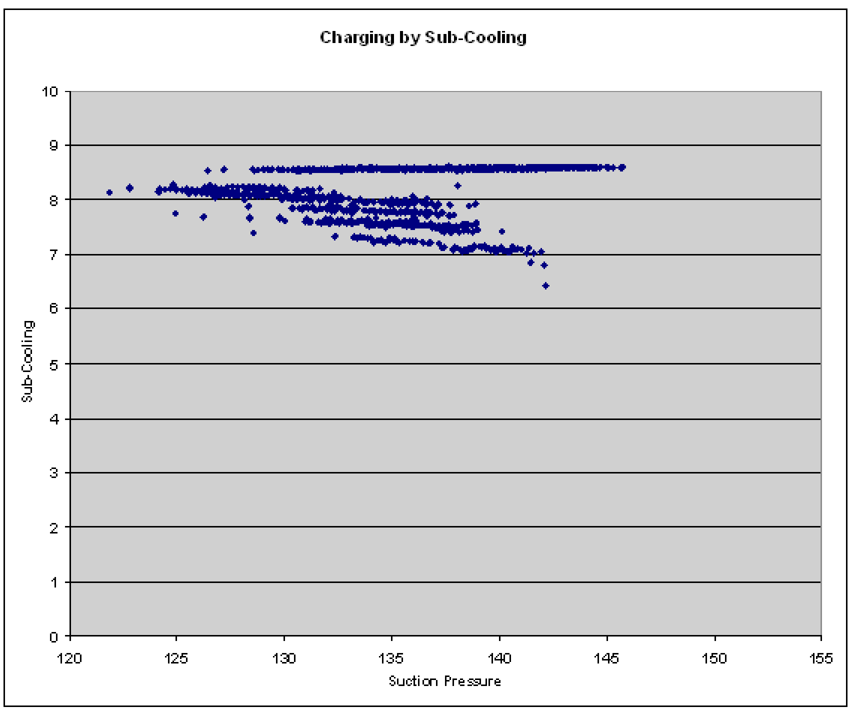


Figure 7: Subcooling Variation with Constant Refrigerant Charge for CASE Study Air Conditioner Tests

When variations with test conditions are combined with achievable limits of measurement variation, it is clear that the existing standard protocol will, at times, produce a "pass" for the contractor and a "fail" for the HERS verifier. This situation produces the question of the sensitivity of efficiency to variations in subcooling and refrigerant charge. The laboratory tests were designed to determine the range of subcooling that would achieve 5% or less variation in efficiency.

Relative Independence of Efficiency from Refrigerant Charge and Subcooling Differences

The efficiency of a TXV unit is nearly constant over a wide range of refrigerant charge and measured subcooling. This is illustrated by laboratory and field tests including the items below.

Figure 7 shows the small variation in efficiency as refrigerant charge is modulated from 20% undercharged to 20% overcharged for TXV systems (dashed lines).

Graph courtesy PG&E Technical and Ecological Services (Report 491-01.4). EER is normalized to the total EER at 95°F outside.

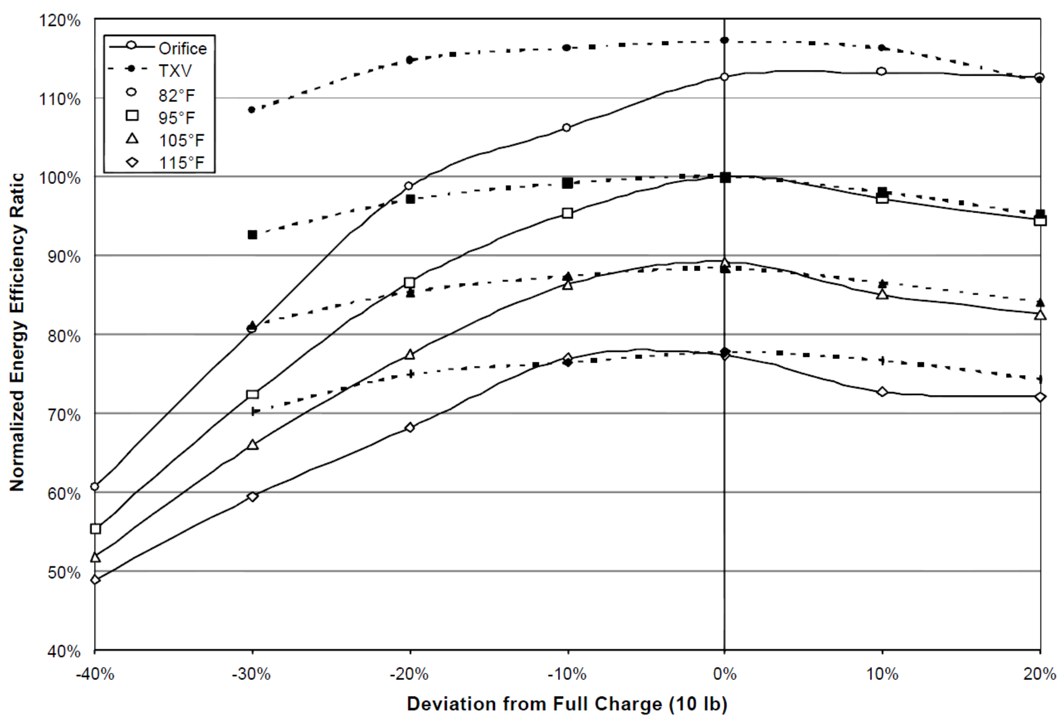


Figure 8: Normalized EER versus Charge and Outside Temperature

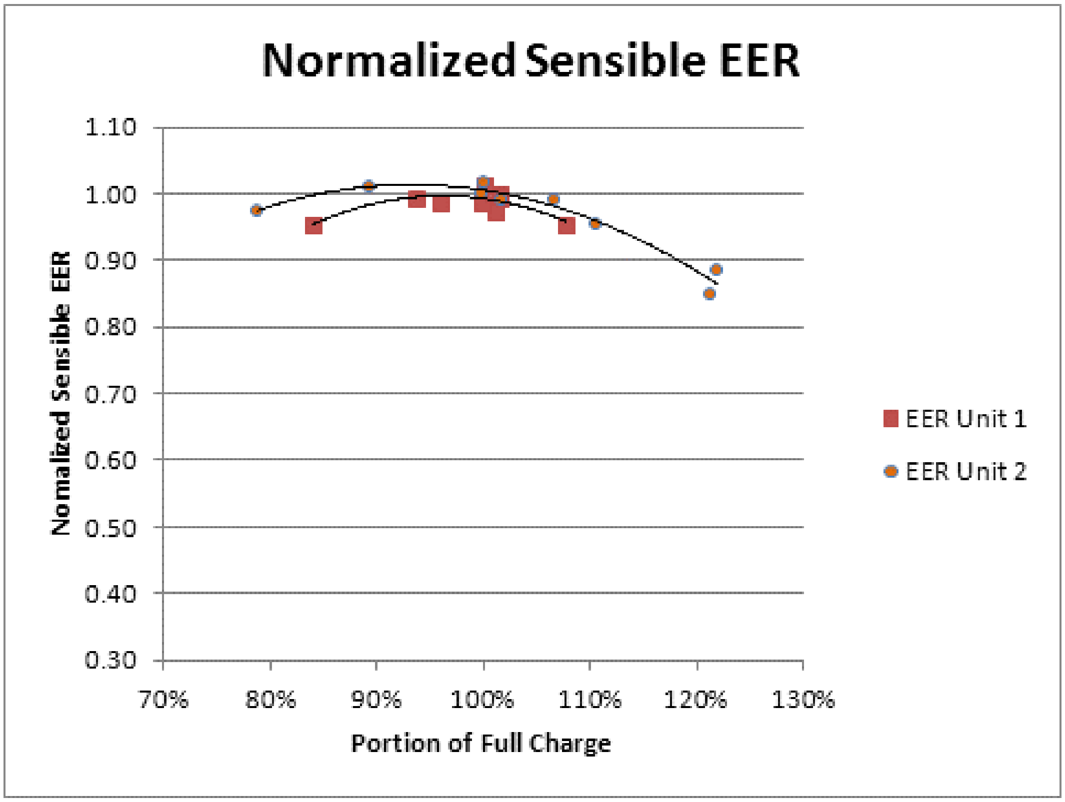


Figure 9: Normalized EER versus Charge in CASE Study at 95°F Outside

Figure 9 shows the same typical efficiency response from the two units tested as part of this CASE study. Sensible EER is normalized to the Sensible EER at full charge (Manufacturer's specified subcooling of 7°F)

The important metric in determining the allowable range of subcooling is how much the Sensible EER changes with refrigerant charge and the indicative subcooling changes. Figure 9 reconfigures the normalized EER curve in Figure 8 to show its relationship to subcooling.

Figure 10 shows the range of subcooling at 95°F in the CASE study as well as the recommended acceptable limits on subcooling by HERS raters.

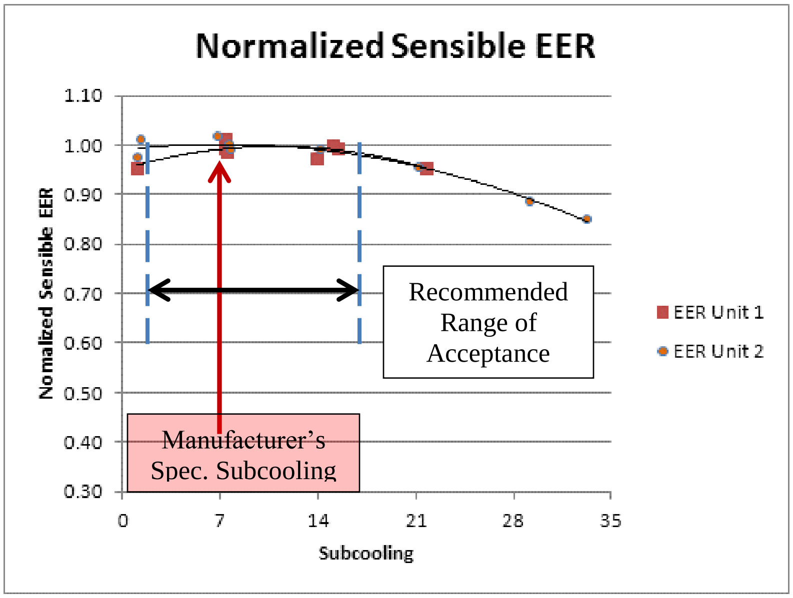


Figure 10: Normalized EER versus Subcooling in CASE Study

Based on the above tests and earlier laboratory testing, an acceptable verification range is proposed.

- On the low end, a minimum subcooling greater than 2°F and no less than target -6°F achieves the goal of limiting efficiency variations due to undercharge. At the same time it does not exclude units for which manufacturers specify a subcooling of 3°F.
- On the high end, a maximum subcooling of target + 6°F over-achieves the goal of limiting efficiency variations due to overcharge.

In all cases the installing technician is still held to the original range of acceptability set by the existing standard and is responsible for charging to the manufacturer's specifications.

As illustrated in Figure 10 the recommended range of acceptance limits the sensible efficiency effect to substantially less than 5%.

4.3.3 Liquid Line Temperature Charging

Partially as a result of the Federal Air Conditioner Standard improvement from SEER 10 to SEER 13, the manufacturers have begun to use refrigerant heat exchangers that have a smaller refrigerant volume. This increases the variation in subcooling with changes in outdoor temperature as well as changes in indoor coil design and airflow. As an example, a microchannel unit was tested and modeled by Trane Company and produced the variations in subcooling shown in Figure 11 (Figure 5 repeated).

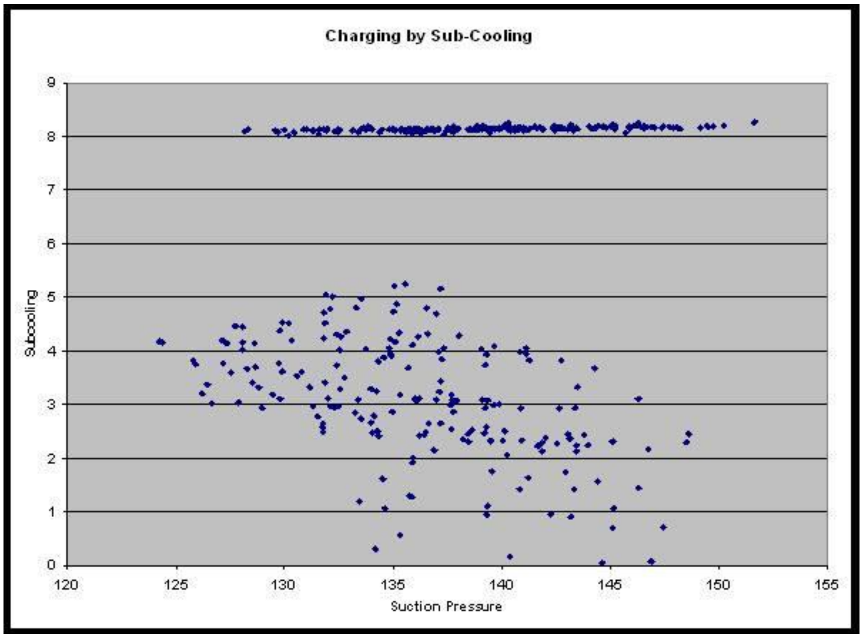


Figure 11: Subcooling at 82°F and 95°F with Constant Refrigerant Charge and Various Matched Indoor Units

The unit depicted is the Trane 4TTM3036A1 with a variety of listed matching indoor units. The graph is from the Trane presentation: “Development of a Charging Method for the 4TTM Family”. The manufacturer found this level of variation unacceptable and has implemented a “Liquid Line Temperature Charging” method that takes into account both the outside temperature and the indoor unit performance.

An example target liquid line temperature table is shown in Figure 12. The liquid line target is determined by the outside temperature and the suction (low side) pressure. The liquid line targets are specific to each model air conditioner.

		4**M3036A1 (** = TT or A7)													
		Outdoor Ambient (°F)													
		<=60	65	70	75	80	85	90	95	100	105	110	115	120	125
		Target (MINIMUM) Liquid Temperature (CHARGE TO BUT NOT BELOW THIS LIMIT)													
Suction Line Pressure (PSIG)	<=115	79	82	84	87	89	92	94	96	100	105	110	115	120	125
	120	81	83	86	88	91	93	95	98	100	105	110	115	120	125
	125	82	85	87	90	92	94	97	99	102	105	110	115	120	125
	130	84	86	88	91	93	96	98	101	103	105	110	115	120	125
	135	85	87	90	92	95	97	100	102	105	107	110	115	120	125
	[illegible]	86	89	91	94	96	99	101	104	106	108	110	115	120	125
	145	88	90	93	95	98	100	102	105	107	110	112	115	120	125
	150	89	92	94	97	99	101	104	106	109	111	114	116	120	125
	155	91	93	95	98	100	103	105	108	110	113	115	117	120	125
	160	92	94	97	99	102	104	107	109	112	114	116	119	121	125
MAXIMUM LIQUID PSIG		241	260	280	301	324	348	373	399	427	455	485	517	549	583
Maximum Allowable Liquid Pressure (DO NOT EXCEED WHEN CHARGING)															

Figure 12. Example of a Liquid Line Charging Table

The CASE team has reviewed data from Trane for unit 4TTM3036A1 and concludes that the indication of desired refrigerant charge is more stable with changing test conditions using the manufacturer's liquid line method rather than the subcooling method.

In the absence of a superior method for charging units that the manufacturer specifies the Liquid Line Charging Method, the CASE team recommends that the Liquid Line Charging Method detailed in 5.3.1 be approved for use by installation technicians and HERS verifiers.

4.3.4 The Effect of Non-condensables on Air Conditioner Efficiency

One persistent problem observed by field inspectors is the prevalence of improper evacuation during AC installation or repairs. The current "state of affairs" is that many installation technicians do not evacuate air and moisture from the refrigerant lines and inside coil prior to opening the valves releasing the stored refrigerant. This process results in misdiagnosis of refrigerant charge (the pressures are elevated above what they would be with pure refrigerant) as well as reduced AC efficiency

This study measured the effect of two evacuation scenarios on air conditioner efficiency. The first scenario is believed to be the most common. In the first scenario nitrogen was introduced into the inside coil and lineset. The service valves remained open to achieve pressure balance with the atmosphere. This simulates to condition wherein the technician makes no attempt or only a marginal attempt to evacuate the system. The second scenario pressurized the inside coil and lineset with 20 psig of nitrogen. This scenario simulates a situation where the technician uses nitrogen for pressure testing, but fails to fully remove it prior to releasing the refrigerant into the system.

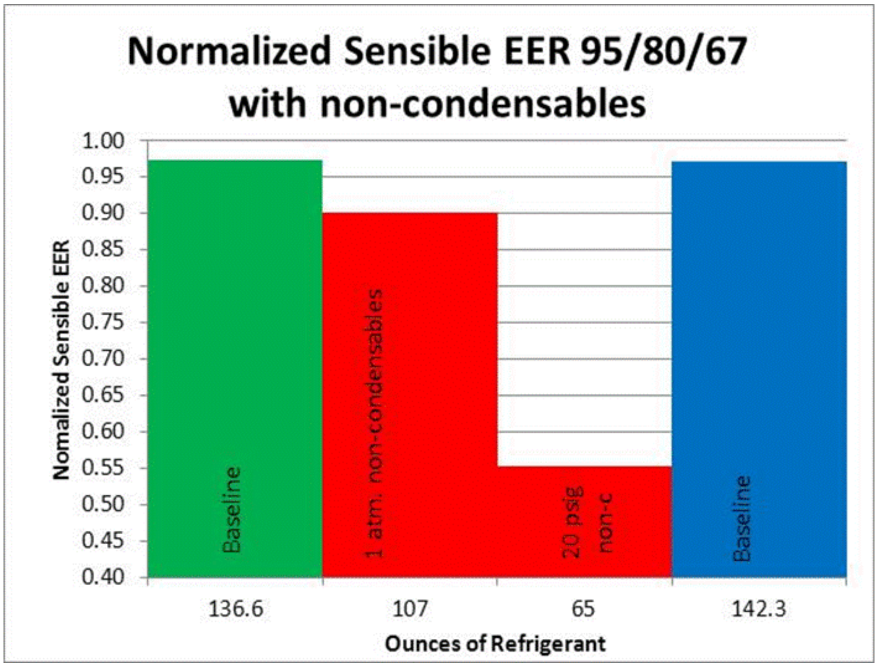


Figure 13: Efficiency Degradation from Non-Condensables in System

The results of the scenario 1 tests as shown in Figure 13 shows failure to evacuate the inside coil and lineset produces a 7.5% reduction in Sensible EER (difference between the green bar and first red bar in Figure 13). This occurred with the manufacturer's nominal (shipped in the unit) refrigerant charge and produced the manufacturer's specified subcooling without any addition or removal of refrigerant (in spite of a 50 foot lineset).

For scenario 2, failure to fully evacuate the nitrogen used for leak testing, required only 4 lbs. and 1 ounce of refrigerant to achieve the manufacturer's specified 7°F subcooling (based on the high side pressure and the assumption of pure refrigerant). This weight of refrigerant is less than half the amount needed to obtain the manufacturer's specified subcooling with this indoor coil and a 50 foot lineset. The hidden lack of refrigerant accounts for the 42% reduction in Sensible EER (difference between the blue bar and second red bar in Figure 13).

4.3.5 Improved Air Conditioner Cycling Test Procedure Accounting for Climate Differences

California utilities are summer peaking with air conditioning causing the increased electric loads at peak demand periods. Peak electric demand dominates the need for additional power plants, transmission infrastructure and causes a variety of environmental problems. Even high-performance air conditioning systems are not optimized to reduce peak electric demand and energy under dry ambient conditions.

Previous research has shown that the cycling test used for establishing SEER is not representative of installed conditions and produces results that are less than optimum for both dry climates and wet climates. In 2008 a coalition of energy advocates and experts had begun an open process to update the Federal Standards. That group had almost universally agreed that there were two fatal flaws in the current air conditioner test procedure. 1) The fan energy consumption and test conditions were totally unrealistic; resulting in inflated ratings. 2) The test did not distinguish between air conditioners that provided good dehumidification for wet climates and superior cooling for hot dry climates. (Buntine, Proctor, and Knight 2008; Energy Solutions 2008; Henderson, Shirey and Raustad 2006; NRDC, NCLC and Enterprise Community Partners 2008; NRDC 2008; Parker et al. 1997; Proctor and Parker 1997; Proctor and Pira 2005; Proctor Engineering Group 2008; Proctor et al. 2008; Sachs 2008)

Previous research including field tests, laboratory tests, and modeling have shown that much of the latent capacity (moisture removal) from air conditioners is actually in storage on the inside coil when the compressor cycle ends. This research has shown that continuing to run the air circulation fan after the compressor stops evaporates the moisture on the coil and delivers it to the building as sensible cooling and rehumidification.

The prior research proved the potential of recovering the stored latent capacity as sensible capacity at low energy cost. There remained a number of questions that these tests and analyses were designed to determine:

- Can certification laboratories provide accurate data for cycle testing at realistic indoor conditions such that the SEER tests could be modified?
- What relationships exist between the rate of airflow, the available stored latent capacity, and latent recovery?
- What are the limitations of latent recovery within the confines of normal duct systems in hot dry climates?

The purpose of this section of the CASE project is to determine how to provide high net sensible EER (defined as sensible capacity with fan heat divided by power with fan watt draw) at high outdoor temperatures, normal dry climate indoor conditions, and typical installation (typical duct system restriction).

Test Description

There were three series of tests covering variations in the evaporator airflow. Each series followed the standard SEER cycling test sequence: compressor on 6 minutes, compressor off 24 minutes, compressor on 6 minutes, compressor off 24 minutes, etc. repeating for five cycles.

The five cycles had increasingly longer fan delays as shown in Figure 14. Figure 15 illustrates the fan delay with the fan running after the compressor powers down.

Cycle	First	Second	Third	Fourth	Fifth
Time	0 sec	105 sec	200 sec	300 sec	610 sec

Figure 14: Fan Delay Setting for Testing

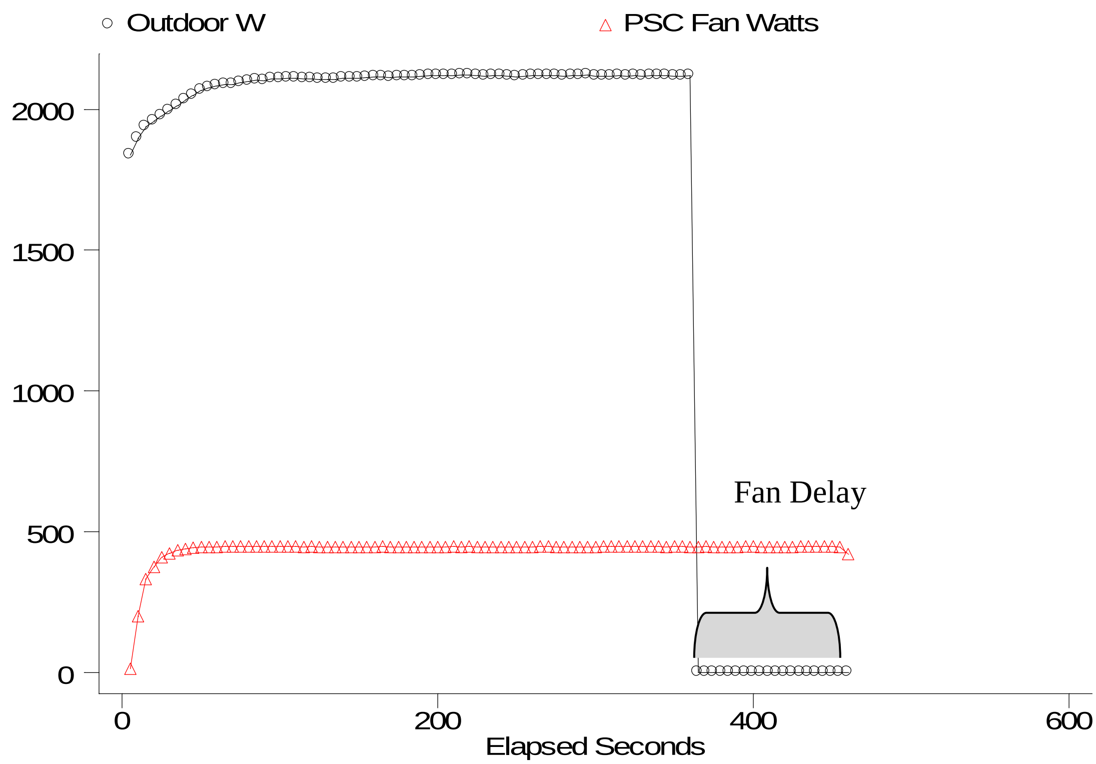


Figure 15: Fan Time Delay Illustration

The airflow through the indoor coil was varied between the test series as shown in Figure 16.

Test Series	0	A	B
Coil Flow Compressor on	450	350	350
Coil Flow Fan Only (Fan Delay)	450	350	216

Figure 16: Indoor Coil Airflow Settings for Tests (CFM per Ton)

Finally, the outdoor and indoor conditions were different from the standard SEER cycling test in order to produce more realistic answers. The outdoor temperature was set at 95°F (SEER is at 82°F). The indoor conditions were held at 80°F dry bulb, 67°F wet bulb (50% Rh). These conditions produce a wet coil as is common in normal operation even in dry climates. The standard SEER test is run with a totally dry indoor coil, which is artificially accomplished by indoor conditions of 80°F dry bulb, 57°F wet bulb.

Calculation

The metric of interest in this research is the performance of the air conditioners at conditions as seen in most of California, Nevada, Arizona, and West Texas. These areas have low outdoor humidity under summer conditions. In these areas the introduction of outdoor air into the building dries the indoor air below 65 grains of moisture (dew point 55 ºF, 0.0093 lb. of water per lb. dry air).

The metric is the Sensible EER.

The Sensible EER is calculated in this manner:

Sensible EER = Net Sensible Capacity / Total Watt Draw

Net Sensible Capacity = Gross Sensible Capacity – Fan Heat

Gross Sensible Capacity = Air Heat Capacity x ($Tevap_{in} - Tevap_{out}$)

Where:

Air Heat Capacity = CFM x density x specific heat capacity
(using appropriate values and conversions)
$Tevap_{in}$ = Temperature entering the evaporator
$Tevap_{out}$ = Temperature leaving the evaporator

Fan Heat = Evap. Fan Watts x 3.412

Total Watt Draw = Compressor Watts + Cond. Fan Watts + Evap. Fan Watts

The following are measured with the laboratory instrumentation: Compressor Watts, Cond. Fan Watts, $Tevap_{in}$, $Tevap_{out}$, and CFM. The air density and air specific heat capacity are calculated based on measured parameters in the test rooms.

The test procedure does not include a standard indoor fan, so simulated values are taken for the Evaporator Fan Watts. The following equations were used to simulate the Evap. Fan Watts:

For a Permanent Split Capacitor Motor Fan
Evap. Fan Watts = 0.51 x CFM

For a Brushless Permanent Magnet Motor Fan
Evap. Fan Watts = 0.000000380682 x CFM^3 - 0.000115317571 x CFM^2 + 0.063091358424 CFM*

Cycle Cumulative Sensible EER

The testing produced instantaneous Net Sensible Capacities and instantaneous Total Watt Draw. When these instantaneous figures are summed over the whole cycle the result is the Cycle Cumulative Sensible EER.

The calculation of Cycle Cumulative Sensible EER is:

$$CyCumSenEER_i = \frac{\sum_{i=0}^{n} Net\ Sensible\ Capacity_i}{\sum_{i=0}^{n} Total\ Watts_i}$$

Where i = seconds from the start of the cycle.

The results for a single cycle from i=0 to i = 660 are shown in Figure 17.

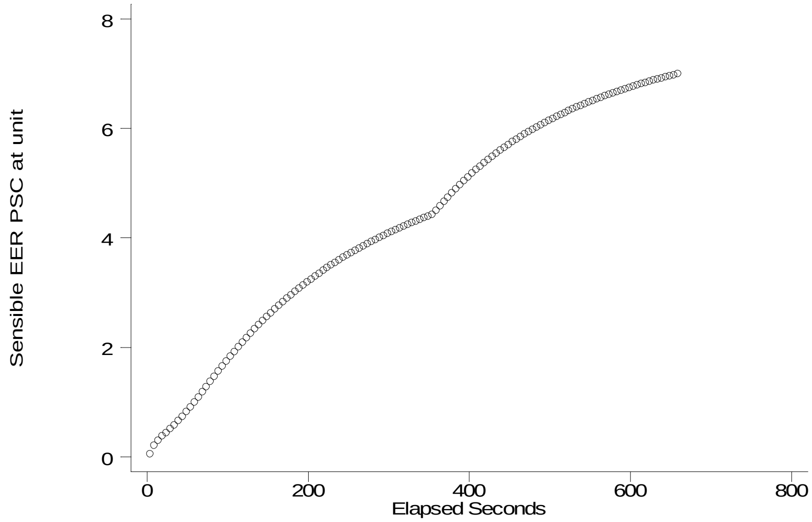


Figure 17: Cumulative Sensible EER vs. Time

Certification Laboratories and Alternative SEER Cycling Tests

The testing at the Intertek laboratory showed that running SEER cycling tests with a wet coil is within their capabilities.

Relationships between Airflow and Latent Recovery

Effect of Airflow on Sensible EER

The first indication of the relationship between airflow and stored latent capacity is the sensible EER of the unit at different airflows. Generally latent capacity is reduced and sensible capacity is increased at higher airflows. These tests confirmed what prior tests have shown. Higher airflow produced higher sensible capacity.

The downside of higher airflows has always been the increase in fan watt draw necessary to obtain the higher airflows. These tests showed that, within the tested range of airflow, the Sensible EER increased in spite of the higher fan watt draws.

Figure 18 shows the increased Sensible EER due to airflow in two identical tests with a 100 second fan delay.

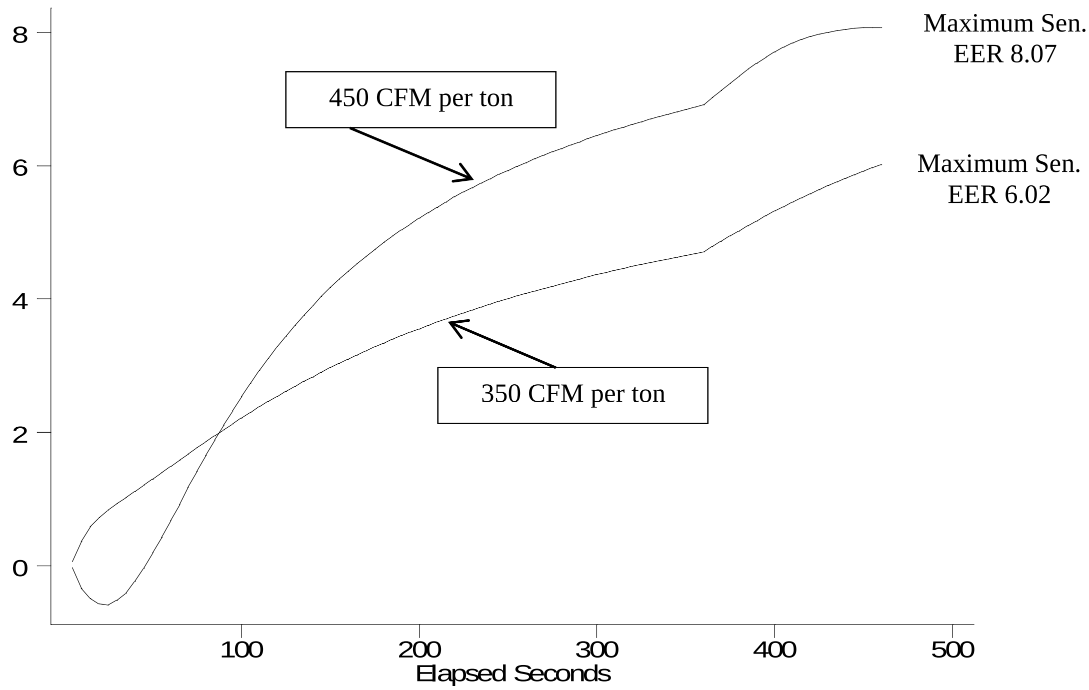


Figure 18: Airflow Effect on Sensible EER (PSC Fan Motor)

In Figure 18 the Sensible EER for the 450 CFM scenario is higher during the compressor part of the cycle. The higher efficiency is due to a larger sensible capacity. When the higher airflows are accomplished, there is less moisture on the coil at the end of the cycle (less latent storage) and the length of the fan delay is limited by the amount of moisture on the coil.

When the performance of the unit is limited by the combination of the duct system and the equipment to 350 CFM per ton (as is most common in field studies) there is more moisture on the coil and the fan delay can be lengthened to achieve higher Sensible EER.

Moisture on the Coil at Start

The length of the previous cycle, the length of the previous fan delay, and the airflow rate all effect the amount of moisture on the coil at the start of the cycle. In all cases with 450 CFM per ton the coil was nearly dry at the beginning of the cycle. This results in a negative Sensible EER during the start-up period. This is shown as the characteristic dip below 0 Sensible EER in Figure 18.

Low Fan Speed during the Fan Delay

It has been proposed that lowering the fan speed during the fan delay combined with a Brushless Permanent Magnet (BPM) motor would produce even higher Sensible EERs due to the low watt draw of the BPM. This hypothesis was investigated with multiple tests. Figure 19 compares two otherwise identical tests; one with the fan speed at 350 CFM per ton and one with 216 CFM per ton during the fan delay.

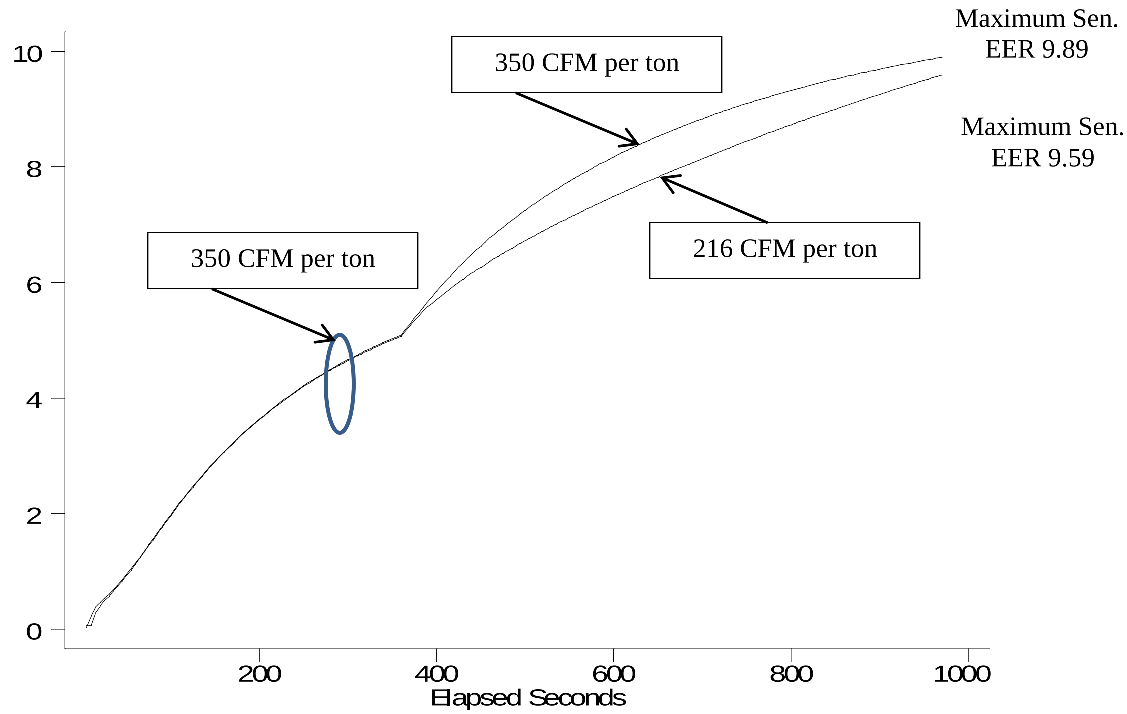


Figure 19: Fan Delay Airflow Effect on Sensible EER (BPM Fan Motor)

Effect of Duct System Efficiency on Sensible EER Delivery

For the BPM motor the lab tests indicate that a long fan delay and lower airflow would be advantageous to produce higher Sensible EERs[3] at the unit. This appearance may be correct for units that have no duct system or have very high distribution efficiencies. However, real ducted systems have conduction and leakage losses. These losses are important to take into account in determining the airflow range and fan delay length.

The laboratory test results were analyzed for connection to a duct system that had a 20% capacity loss at full capacity. This was modeled as:

Capacity Loss = C x (120°F – T_{supply}*)* while the fan is operating.

Where *C* is a constant.

Duct losses modify the Sensible EER results substantially. Figure 20 shows the results for a PSC motor and 350 CFM per ton with and without duct losses.

3 See Figure 23.

Duct loss effect with a PSC fan motor

Without duct losses the peak Sensible EER in Figure 20 occurs with the longest fan time delay (610 seconds). The Sensible EER peak occurs at the end of the time delay with a value of 7.30 BTU/watt hr.

With duct losses the peak occurs with the shorter time delay at 3.89 BTU/watt hr.

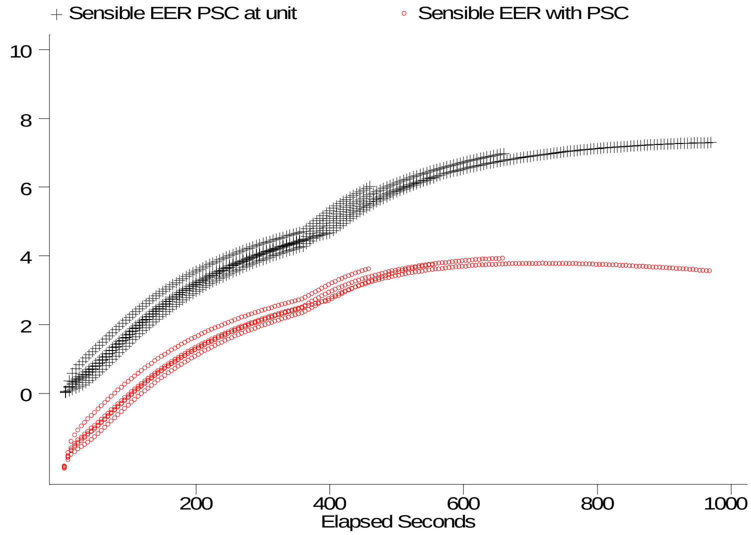


Figure 20: Duct Loss Effect on Sensible EER (350 CFM, PSC Fan Motor)

Duct loss effect with a BPM fan motor

The duct losses have a similar effect on the unit's Sensible EER when it is fitted with a BPM motor. These results are shown in Figure 21. Without duct losses the peak Sensible EER (9.89 BTU/watt hr.) occurs with the longest fan delay.

With duct losses the peak Sensible EER (5.23 BTU/watt hr.) in Figure 21 occurs at a 525 second time delay.

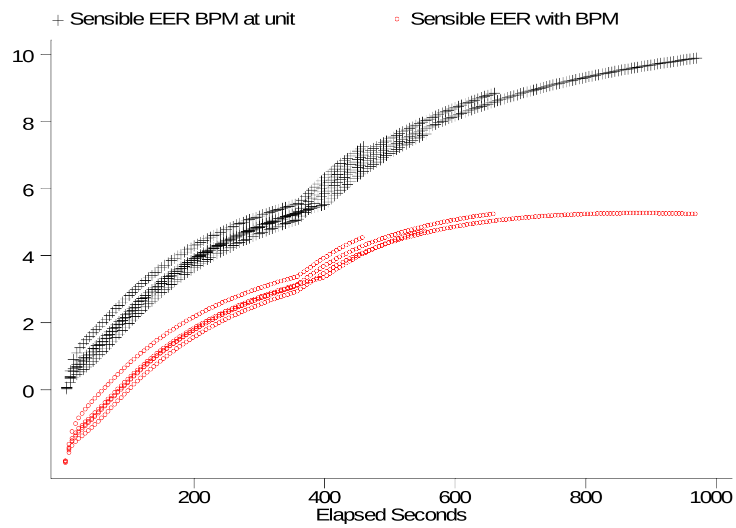


Figure 21: Duct Loss Effect on Sensible EER (350 CFM, BPM Fan Motor)

Duct loss effect with a BPM fan motor at 450 CFM per ton

When the system can attain a 450 CFM per ton airflow, the duct loss effect does not significantly affect the optimum fan delay; however it has an obviously detrimental effect on the Sensible EER delivered. The peak Sensible EER is 8.92 without duct losses and 6.58 with the assumed duct losses.

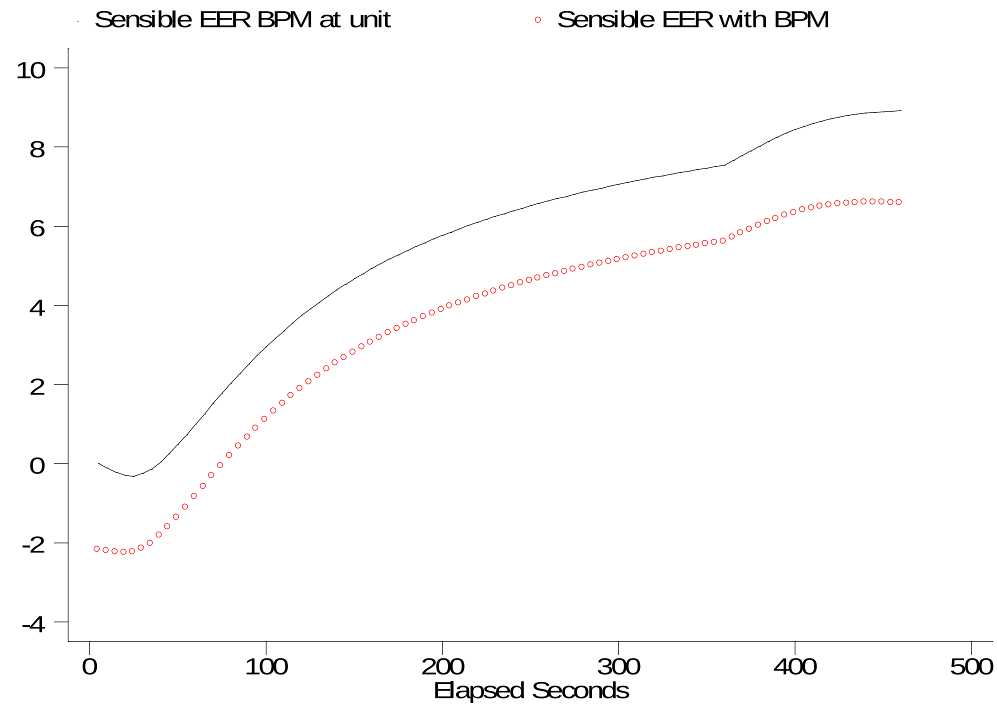


Figure 22: Duct Loss Effect on Sensible EER (450 CFM, BPM Fan Motor)

Summary

Figure 23 summarizes the maximum Sensible EERs for PSC units and the time delay at which that maximum occurs.

Cycle	Flow	350 CFM/ton	450 CFM/ton	350 - 216 CFM/ton
Second (105 sec cycle fan delay)	Maximum Sensible EER no ducts	6.01	8.07	4.82
	Fan delay at Maximum	100	100	105
	Maximum Sensible EER with ducts	3.59	5.91	2.41
	Fan delay at Maximum	100	80	105
Third (200 sec cycle fan delay)	Maximum Sensible EER no ducts	6.26	7.65	5.49
	Fan delay at Maximum	195	100	190
	Maximum Sensible EER with ducts	3.70	5.48	2.66
	Fan delay at Maximum	195	80	185
Fourth (300 sec cycle fan delay)	Maximum Sensible EER no ducts	6.98	7.40	6.04
	Fan delay at Maximum	300	105	315
	Maximum Sensible EER with ducts	3.89	5.23	2.78
	Fan delay at Maximum	300	85	240
Fifth (610 sec cycle fan delay)	Maximum Sensible EER no ducts	7.30	7.30	6.86
	Fan delay at Maximum	610	105	610
	Maximum Sensible EER with ducts	3.75	5.13	2.89
	Fan delay at Maximum	360	80	250

Figure 23: Sensible EER Summary for PSC Unit

Figure 24 summarizes the maximum Sensible EERs for BPM unit and the time delay at which that maximum occurs.

Cycle	Flow	350 CFM/ton	450 CFM/ton	350 - 216 CFM/ton
Second (105 sec cycle fan delay)	Maximum Sensible EER no ducts	7.25	8.92	5.90
	Fan delay at Maximum	100	100	105
	Maximum Sensible EER with ducts	4.50	6.58	3.18
	Fan delay at Maximum	100	85	105
Third (200 sec cycle fan delay)	Maximum Sensible EER no ducts	7.63	8.47	6.90
	Fan delay at Maximum	195	115	190
	Maximum Sensible EER with ducts	4.71	6.12	3.62
	Fan delay at Maximum	195	85	190
Fourth (300 sec cycle fan delay)	Maximum Sensible EER no ducts	8.85	8.20	7.84
	Fan delay at Maximum	300	120	315
	Maximum Sensible EER with ducts	5.21	5.85	3.94
	Fan delay at Maximum	300	90	315
Fifth (610 sec cycle fan delay)	Maximum Sensible EER no ducts	9.89	8.10	9.59
	Fan delay at Maximum	610	115	610
	Maximum Sensible EER with ducts	5.23	5.74	4.24
	Fan delay at Maximum	525	85	590

Figure 24: Sensible EER Summary for BPM Unit

4.3.6 Laboratory Tests of Charge Indicator Display

Title 24 provides the Charge Indicator Display (CID) as an alternative to refrigerant charge checking. The benefit of the CID is that it continuously monitors the air conditioner and informs the occupant when there are specific problems with the unit. The Indicator Display takes a “motion picture” of AC performance, while refrigerant charge checking is a “snap shot”.

Potential manufacturers were given the opportunity to test prototype CIDs during the test sequence. Two Charge Indicator Displays were installed in the Intertek laboratory for this study. Both units correctly identified undercharge in the early testing.

The statuses of the CIDs in the summary sheets for September 20 through September 23 were not recorded. During that time there was one test that should produce a fault indication. Beginning September 28 a new unit was tested and the CIDs monitored. One of the two units properly indicated an undercharge fault when it occurred.

On September 30 a fault indication was not recorded for either CID at a test condition with significant undercharge. The identical test was repeated on October 2 and one of the two units properly indicated the overcharge situation.

There were no false indications of charge or airflow problems with either device.

Both potential manufacturers appreciated the opportunity to test their devices and are continuing development and manufacturing plans.

4.4 Conclusions

4.4.1 Acceptance Limits for HERS Verification

The current acceptance limits for HERS verification are too narrow to avoid false failures at the time of the HERS verification test. The acceptance limits should be widened to account for differences in test conditions.

The new limits should be based on the potential sensible efficiency effect of the limits.

4.4.2 Test Protocol for Winter Testing of Air Conditioners

On TXV air conditioners refrigerant charge can be successfully adjusted using a low temperature protocol that restricts the outflow from the condenser to achieve appropriate pressure drops across the TXV.

The proposed protocol achieves Sensible EERs that are within 2% of the Sensible EERs using the common summer charge test protocol.

4.4.3 Liquid Line Temperature Charging

Charging to a target liquid line temperature is a valid method of obtaining uniform refrigerant charge levels at differing outdoor temperatures and differing indoor conditions.

Charging to a target liquid line temperature based on the condenser air entering temperature and suction pressure produces superior charging results on low volume coils and should be accepted as an alternative method where the manufacturer specifies that method.

4.4.4 Non-Condensables and Improper Evacuation

Improper evacuation leaves non-condensables mixed with the refrigerant. This condition produces erroneous determination of saturation temperatures and significantly reduced Sensible EER.

Even a mild amount of non-condensables produce a 7.5% reduction in Sensible EER.

4.4.5 Improved Air Conditioner Cycling Test Procedure Accounting for Climate Differences

Testing at Intertek showed that commonly used certification laboratories can run valid cycling test at conditions more representative than the current SEER cycling test.

The revised test can produce metrics of significant meaning and usefulness for both dry climates and moist climates by differentiating between high Sensible EER and high Latent or Total EER.

When the improved cycling test procedure is used the following practical implications are made apparent:

- For ducted systems installed outside the conditioned space with near 6 minute compressor cycles and airflow near 350 CFM per ton, the optimum time delay is approximately 300 seconds (five minutes) for a PSC fan motor machine.
- For similar conditions to a) above, the optimum time delay for a BPM fan motor machine is approximately 525 seconds (near nine minutes).
- For units capable of high airflows near 450 CFM per ton, the optimum fan delay is near 90 seconds regardless of the fan motor if the duct losses are 20% or less.
- For non-ducted units, or units with near zero duct losses and common 350 CFM per ton, the optimum fan delay for either type of fan motor is approximately ten minutes.
- At common conditions of 350 CFM per ton and 20% duct losses, the addition of a 5 minute fan delay increases a PSC unit Sensible EER from 2.45 to 3.89, a potential savings of 37%.
- At common conditions of 350 CFM per ton and 20% duct losses, the addition of a 10 minute fan delay increases a BPM Sensible EER from 3.07 to 5.23, a potential savings of 41%.

4.4.6 Charge Indicator Displays

Charge indicator Displays (CIDs) show promise in providing constant monitoring of air conditioners. The laboratory tests showed that two manufacturers are close to producing units that can meet the Title 24 specifications.

5. Recommended Language for the Reference Appendices

5.1 Revise RA3.2 Procedures for Determining Refrigerant Charge for Split System Space Cooling Systems Without a Charge Indicator Display

5.1.1 RA3.2.1 Purpose and Scope

The purpose of this procedure is to determine and verify that residential split system space cooling systems and heat pumps have the required refrigerant charge and that the metering device is working as designed. The procedures only apply to ducted split system central air conditioners and ducted split system central heat pumps. The procedures do not apply to packaged systems. For dwelling units with multiple split systems or heat pumps, the procedure shall be applied to each system separately. The procedures detailed in Section RA3.2 are to be used after the HVAC installer has installed and charged the air conditioner or heat pump system in accordance with the manufacturer's instructions and specifications. Failure to follow the manufacturer's instructions may result in significant refrigeration system faults that may invalidate refrigerant charge and metering device results.

The installer shall certify to the builder, building official and HERS rater that he/she has followed the manufacturer's instructions and specifications prior to proceeding with the procedures in this appendix.

Appendix RA3.2 defines three procedures, the Standard Charge Measurement Procedure and the Liquid Line Temperature Charging Method in Section RA3.2.2, the Alternate Charge Measurement Procedure in Section RA3.2.3, The standard procedure or liquid line temperature procedure shall always be used for HERS rater verification. HVAC installers may use the alternate procedure when the outdoor temperature is below 70°F.

Refrigerant charging procedures other than that described in RA3.2 are possible, and when vapor compression air conditioner and heat pump system refrigerant charge and metering device operating performance can be reliably determined by methods and instrumentation other than those specifically defined in section RA3.2, such alternative charging procedures shall be allowed if the air conditioner equipment manufacturer requests approval from the Executive Director. The Executive Director will grant such approval after reviewing submittals from the applicant. Charging procedures that are approved by the Executive Director will be published as an addendum to this appendix.

The applicant shall provide information that specifies the required instrumentation, the instrumentation accuracy, the parameters measured, the required calculations, the allowable deviations from target values for system operating parameters, and the requirements for system fault indication. Manufacturers shall certify to the Energy Commission that the charging procedure produces a sensible EER at 95/80/67 that is within 5% of the sensible EER produced in a laboratory test at 95/80/67 of the air conditioner with the designated refrigerant weight. Manufacturers using alternative charging procedures shall, upon request, provide comprehensive engineering specification documentation, installation and technical field service documentation, and user instructions documentation to installers and service personnel that utilize the procedure.

The following sections document the instrumentation needed, the required instrumentation calibration, the measurement procedure, and the calculations required for each procedure.

The reference method algorithms adjust (improve) the efficiency of split system air conditioners and heat pumps when they are diagnostically tested to have the correct refrigerant charge and the metering device is operating properly. Table RA3.2-1 summarizes the algorithms that are affected by refrigerant charge testing.

Table RA3.2-1 – Summary of Diagnostic Measurements

Input to the Algorithms	Description	Standard Design Value	Proposed Design	
			Default Value	Procedure
Cooling System Refrigerant Charge and Metering	F_{CID} takes on a value of 0.96 when the system has been diagnostically tested for the correct refrigerant charge, or a charge Indicator Display is field verified. Otherwise, F_{CID} has a value of 0.90.	Split systems are assumed to have refrigerant charge testing or a Charge Indicator Display when required by Package D.	No refrigerant charge testing or Charge Indicator Display.	RA3.2.2 or RA3.2.3

Note that diagnostically testing the refrigerant charge requires a minimum level of airflow across the evaporator coil, as specified in the Section 150 of the Standards.

5.1.2 RA3.2.2 Standard Charge Measurement Procedure

This section specifies the Standard charge measurement procedure. Under this procedure, required refrigerant charge is calculated using:

1. The Superheat Charging Method for Fixed Metering Devices or
2. The Subcooling Charging Method for Thermostatic Expansion Valves (TXV) and Electronic Expansion Valves (EXV), or
3. The Liquid Line Temperature Charging Method, or
4. An Alternative Charging Method specified by the Manufacturer and approved by the Executive Director.

The standard procedures detailed in this section shall be completed within the manufacturer's specified temperature range after the HVAC installer has installed and charged the system in accordance with the manufacturer's specifications. All HERS rater verifications are required to use a standard procedure.

This procedure does not relieve the installing contractor from any obligations to follow manufacturers' specifications. This procedure is used to assure conformance to Title 24.

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NOTE: All intervening sections remain as is.

5.1.3 RA3.2.2.2 Instrumentation Specifications

Instrumentation for the procedures described in this section shall conform to the following specifications:

RA3.2.2.2.1 *Digital Thermometer*

Digital thermometer shall have dual channel capability in Celsius or Fahrenheit readout with: 1. Accuracy: ± ±1.8°F, 2. Resolution: 0.2º F.

RA3.2.2.2.2 Temperature Sensors and Temperature Measurement Access Holes (TMAH)

Measurements require three (3) temperature sensors that pass the following test:

1. A test point at dry bulb temperature T_1
2. The temperature sensor stabilized at T_2
3. The absolute value of (T_1 minus T_2) is greater than 40ºF
4. When the sensor is moved to the test point, the sensor has a response time that produces the accuracy specified in Section RA3.2.2.2.1 within 90 seconds of insertion.

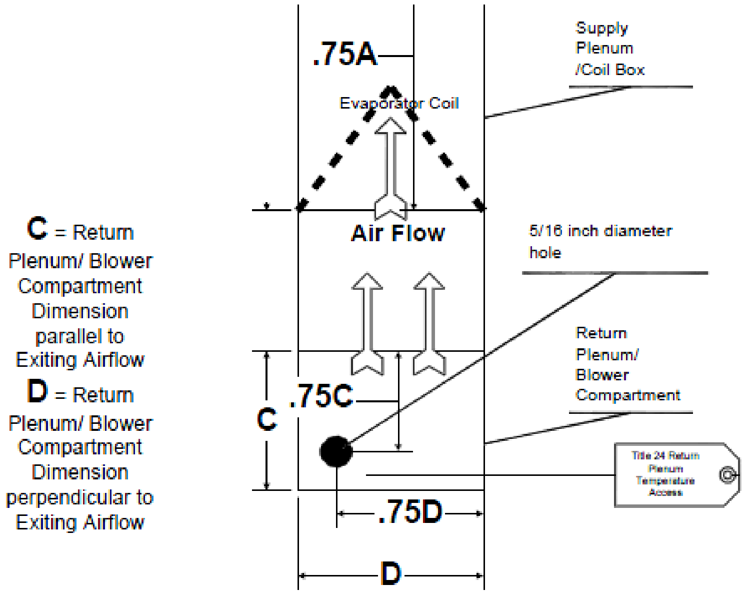
Measurements require one (1) cotton wick for measuring wet-bulb temperatures or an electronic gauge that is calibrated to be within the tolerances in ***RA3.2.2.2.1***

Measurements require two (2) pipe temperature sensors that pass the following test:

1. Six pipes (1/4" dia., 3/16" dia., 3/8" dia., 3/4" dia., 7/8" dia., 1 1/8" dia.) at temperature T_1 in an environment at T_2 where the absolute value of (T_1 minus T_2) is greater than 40ºF
2. The temperature sensor is stabilized at T_2
3. The sensor has a response time that produces the accuracy specified in Section RA3.2.2.2.1 within 90 seconds of application to the pipe of the size for which it is approved.

A sensor may be used for more than one pipe size if it passes the above test for each pipe size for which it is used.

There shall be one labeled temperature measurement access hole in the supply plenum. The temperature measurements shall be taken at the following location:



The location shall have a 5/16" (8 mm) diameter hole. The location shall be labeled "Title 24 – Return Temperature Access" in at least 12-point type. This location can be in any one of the four sides of the plenum.

RA3.2.2.3 Digital Refrigerant Gauges

A digital refrigerant gauge with an accuracy of ±3 psig discharge pressure and ±1.0 psig suction pressure shall be used. Other saturation temperature measurement sensor instrumentation methodologies shall be allowed if the specifications for the methodologies are approved by the Executive Director.

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5.1.4 RA3.2.2.5 Set up for Charge Measurement

Except for winter charging using the Standard method, the unit should be set up as it normally operates.

For winter charging using the Standard method, the unit should be set up as described in this section if the manufacturer has approved the use of this winter charging method:

1. Install the condenser outlet air restrictor on the outlet from the condenser fan:

   a. Position the restrictor so it does not interfere with the inlet airflow to the condenser.

   b. Start the air conditioner or heat pump in the cooling mode and restrict the outlet until the difference between the high side pressure and the low side pressure is between 160 psi and 220 psi for R-410A refrigerant and 100 to 145 psi for R-22 refrigerant.

      160 psi ≤ (Phigh, – Plow) ≤ 220 psi for R-410A refrigerant;

      100 psi ≤ (Phigh, – Plow) ≤ 145 psi for R-22 refrigerant

   c. Allow the unit to stabilize for 15 minutes, make sure the pressure is still

      160 psi ≤ (Phigh, – Plow) ≤ 220 psi for R-410A refrigerant

      100 psi ≤ (Phigh, – Plow) ≤ 145 psi for R-22 refrigerant 2.

Note 1: Refer to Energy Commissions website for the list of split system air condition units approved by the manufacturers to use the Winter Charge Setup. In addition to the requirements of this document, manufacturers may issue additional instructions/clarification for the equipment and procedures to be used to conduct the Winter Charge Setup. These additional instruction/clarifications are also available on the Energy Commission website. http://www.energy.ca.gov/title24/

Note 2: Winter Charge Setup may be used for manufacturer approved systems that use a target subcooling for refrigerant charge, including units equipped with micro-channel heat exchangers where the manufacturer specifies subcooling for measuring refrigerant charge.

Note 3: Similar to the Standard Charge Measurement Procedure for warm weather, the Winter Charge Setup may be used by the Installer and/or the HERS Rater.

5.1.5 RA3.2.2.5 Charge Measurement

The following procedure shall be used to obtain measurements necessary to adjust required refrigerant charge as described in the following sections:

1. If the condenser air entering temperature is less than 65ºF, establish a return air dry bulb temperature sufficiently high at the beginning of the test that the return air dry bulb temperature will be not less than 70ºF at the end of the 15-minute period in step 2.

2. Connect the refrigerant gauges to the service ports, taking normal precautions to not introduce air into the system.

3. Turn the cooling system on and let it run for 15 minutes to stabilize temperatures and pressures before taking any measurements. While the system is stabilizing, proceed with setting up the temperature sensors.

4. Attach one pipe temperature sensor to the suction line near the suction line service valve, with the sensor on the top of the pipe between 10 o'clock and 2 o'clock, and attach one pipe temperature sensor to the liquid line near the liquid line service valve.

5. Attach a temperature sensor to measure the condenser entering air dry-bulb temperature. The sensor shall be placed so that it records the average condenser air entering temperature and is shaded from direct sun.

6. Ensure that all cabinet panels that affect airflow are in place before making measurements. The temperature sensors shall remain attached to the system until the final charge is determined.

7. If a fixed metering device using a cotton wick sensor, place wet-bulb temperature sensor (cotton wick) in water to ensure it is saturated when needed. Do not get the dry-bulb temperature sensors wet.

8. At 12 minutes, insert a dry-bulb temperature sensor (and a wet-bulb temperature sensor if a fixed metering device) into the return plenum at the "Title 24 – Return Temperature Access" detailed in Section RA3.2.2.2.2.

9. At 15 minutes when the return plenum wet-bulb temperature reading has stabilized (if present), using the temperature sensors already in place, measure and record the return (evaporator entering) air dry-bulb temperature ($T_{return,\ db}$) and the return (evaporator entering) air wet-bulb temperature ($T_{return,\ wb}$) (if present).

10. Using the refrigerant gauge or saturation temperature measurement sensor already attached, measure and record the evaporator saturation temperature ($T_{evaporator,\ sat}$) from the low side gauge.

11. Using the refrigerant gauge or saturation temperature measurement sensor already attached, measure and record the condenser saturation temperature ($T_{eondenser,\ sat}$) from the high side gauge.

12. Using the pipe temperature sensor already in place, measure and record the suction line temperature ($T_{suction,}$).

13. Using the pipe temperature sensor already in place, measure and record the liquid line temperature (T_{liquid}).

14. Using the dry-bulb temperature sensor already in place, measure and record the condenser (entering) air dry-bulb temperature ($T_{condenser,\ db}$).

The above measurements shall be used to adjust refrigerant charge as described in following sections.

5.1.6 RA3.2.2.6 Refrigerant Charge and Metering Device Calculations

The following steps describe the calculations to determine if the system meets the required refrigerant charge and metering device function using the measurements described in Section RA3.2.2.5. If a system fails, then remedial actions must be taken. Be sure to run the air conditioner for 15 minutes after the final adjustments before taking any measurements.

RA3.2.2.6.1 Fixed Metering Device Calculations

The Superheat Charging Method is used only for systems equipped with fixed metering devices. These include capillary tubes and piston-type metering devices.

1. Calculate Actual Superheat as the suction line temperature minus the evaporator saturation temperature. *Actual Superheat* = $T_{suction,} – T_{evaporator,\ sat}$.

2. Determine the Target Superheat using Table RA3.2-2 using the return air wet-bulb temperature ($T_{return,\ wb}$) and condenser air dry-bulb temperature ($T_{condenser,\ db}$).

3. If a dash mark is read from Table RA3.2-2, the target superheat is less than 5°F. Note that **a valid refrigerant charge verification test cannot be performed under these conditions**. A severely undercharged unit will show over 9°F of superheat. However overcharged units cannot be detected from the superheat method. The usual reason for a target superheat determination of less than 5°F is that outdoor conditions are too hot and the indoor conditions are too cool. One of the following is needed so a target superheat value can be obtained from Table RA3.2-2 either 1) turn on the space heating system and/or open the windows to warm up indoor temperature; or 2) retest at another time when conditions are different. Repeat the measurement procedure as necessary to establish the target superheat. Allow system to stabilize for 15 minutes before the final measurements are taken.

4. Calculate the difference between actual superheat and target superheat (Actual Superheat - Target Superheat).

5. In order to allow for inevitable differences in measurements, the Pass/Fail criteria are different for the Installer and the HERS Rater. For the Installer, if the difference is between minus 5°F and plus 5°F, then the system **passes** the required refrigerant charge criterion. For the HERS Rater inspecting the system, if the difference is between minus 8°F and plus 8°F, then the system **passes** the required refrigerant charge criterion.

6. For the Installer, if the difference is greater than plus 5°F, then the system **does not pass** the required refrigerant charge criterion and the Installer shall add refrigerant. Adjust refrigerant charge and check the measurements as many times as necessary to pass the test. After the final adjustment has been made, allow the system to run 15 minutes before completing the final measurement procedure.

7. For the Installer, if the difference is between minus 5°F and minus 100°F, then the system **does not pass** the required refrigerant charge criterion, the Installer shall remove refrigerant. Adjust refrigerant charge and check the measurements as many times as necessary to pass the test. After the final adjustment has been made, allow the system to run 15 minutes before completing the final measurement procedure.

RA3.2.2.6.2 Variable Metering Device Calculations

The Subcooling Charging Method is used for systems equipped with variable metering devices. These include Thermostatic Expansion Valves (TXV) and Electronic Expansion Valves (EXV). The amount of refrigerant is set based on the subcooling and the superheat determines whether the device is working properly.

1. Calculate Actual Subcooling as the liquid line temperature minus the condenser saturation temperature. Actual Subcooling = $T_{condenser, sat} - T_{liquid}$

2. Determine the Target Subcooling specified by the manufacturer.

3. Calculate the difference between actual subcooling and target subcooling (Actual Subcooling **-** Target Subcooling

4. In order to allow for inevitable differences in measurements, the Pass/Fail criteria are different for the Installer and the HERS Rater.

    a. For the Installer, If the difference is between minus 3°F and plus 3°F inclusive, then the system **passes** the required refrigerant charge criterion.

    b. For the HERS Rater inspecting the system, if the difference is between minus 6°F and plus 6°F inclusive and the subcooling is greater than 2°F, then the system **passes** the required refrigerant charge criterion

5. For the Installer, if the difference is greater than plus 3°F, then the system **does not pass** the required refrigerant charge criterion and the Installer shall remove refrigerant. Adjust refrigerant charge and check the measurements as many times as necessary to pass the test. After the final adjustment has been made, allow the system to run 15 minutes before completing the final measurement procedure.

6. For the Installer, if the difference is between minus 3°F and minus 100°F, then the system **does not pass** the required refrigerant charge criterion, the Installer shall add refrigerant. Adjust refrigerant charge and check the measurements as many times as necessary to pass the test. After the final adjustment has been made, allow the system to run 15 minutes before completing the final measurement procedure.

7. Calculate Actual Superheat as the suction line temperature minus the evaporator saturation temperature. Actual Superheat = $T_{suction} - T_{evaporator, sat}$.

8. If possible, determine the Superheat Range specified by the manufacturer.

9. In order to allow for inevitable differences in measurements, the Pass/Fail criteria are different for the Installer and the HERS Rater.

a. For the Installer, if the superheat is within the manufacturer's superheat range, then the system **passes** the metering device criterion. If the manufacturer's specification is not available and the superheat is between 4°F and 25°F, then the system **passes** the metering device criterion.

b. For the HERS Rater inspecting the system, if the superheat is between 3°F and 26°F, then the system **passes** the metering device criterion.

5.1.7 RA3.2.XXX Liquid Line Temperature Charging Method

The Liquid Line Temperature Charging Method is used only for systems which the manufacturer specifies that charging method and provides a target liquid line temperature based on the operating conditions. An example of one manufacturer's target liquid line temperature table is reproduced below. This method improves the accuracy of refrigerant charging particularly in units with low refrigerant volume in the condenser (such as microchannel heat exchangers).

		Model Number ABCDEFG											
		Outdoor Ambient (°F)											
		60	65	70	75	80	85	90	95	100	105	110	115
		MINIMUM LIQUID LINE TEMPERATURE (°F)											
Suction Line Pressure (psig)	<=115	T11	T12	T13	T14	T15	T16	T17	T18	T19	T110	T111	T112
	120	T21	T22	T23	T24	T25	T26	T27	T28	T29	T210	T211	T212
	125	T31	T32	T33	T34	T35	T36	T37	T38	T39	T310	T311	T312
	130	T41	T42	T43	T44	T45	T46	T47	T48	T49	T410	T411	T412
	135	T51	T52	T53	T54	T55	T56	T57	T58	T59	T510	T511	T512
	140	T61	T62	T63	T64	T65	T66	T67	T68	T69	T610	T611	T612
	145	T71	T72	T73	T74	T75	T76	T77	T78	T79	T710	T711	T712
	150	T81	T82	T83	T84	T85	T86	T87	T88	T89	T810	T811	T812
	155	T91	T92	T93	T94	T95	T96	T97	T98	T99	T910	T911	T912
	160	T101	T102	T103	T104	T105	T106	T107	T108	T109	T1010	T1011	T1012
MAX. LIQUID PRESS.		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
		DO NOT EXCEED MAXIMUM ALLOWABLE LIQUID PRESSURE (psig)											

Simulated Liquid Line Temperature Target Table

The procedure for charging these units is:

1. Follow the manufacturer's directions and adhere to their limitations on indoor and outdoor temperatures appropriate to this procedure.
2. Start the unit air conditioner and allow it to stabilize for 15 minutes.
3. Measure the liquid line temperature T_{liquid}, the low side pressure, $P_{low,}$ and the liquid (high side) pressure P_{high}.
4. Determine the minimum liquid line temperature and maximum high side pressure from the manufacturer's table.
5. Determine the difference between the liquid line temperature and the minimum liquid line temperature (Actual Temperature – Minimum Temperature).

6. In order to allow for inevitable differences in measurements, the Pass/Fail criteria are different for the Installer and the HERS Rater.
    a. For the Installer, If the difference is between minus 0°F and plus 2°F (inclusive) AND the high side pressure is less than the listed maximum liquid (high side) pressure , then the system **passes** the required refrigerant charge criterion.
    b. For the HERS Rater inspecting the system, if the difference is between minus 2 °F and plus 4°F (inclusive), then the system **passes** the required refrigerant charge criterion
7. For the Installer, if the difference is greater than plus 2°F and less than the maximum high side pressure, then the system **does not pass** the required refrigerant charge criterion, the Installer shall add refrigerant. Adjust refrigerant charge and check the measurements as many times as necessary to pass the test. After the final adjustment has been made, allow the system to run 15 minutes before completing the final measurement procedure.
8. For the Installer, if the difference is negative, then the system **does not pass** the required refrigerant charge criterion and the Installer shall remove refrigerant. Adjust refrigerant charge and check the measurements as many times as necessary to pass the test. After the final adjustment has been made, allow the system to run 15 minutes before completing the final measurement procedure.
9. Calculate Actual Superheat as the suction line temperature minus the evaporator saturation temperature. Actual Superheat = $T_{suction}$, $- T_{evaporator, sat}$.
10. If possible, determine the Superheat Range specified by the manufacturer.
11. In order to allow for inevitable differences in measurements, the Pass/Fail criteria are different for the Installer and the HERS Rater.
    a. For the Installer, if the superheat is within the manufacturer's superheat range, then the system **passes** the metering device criterion. If the manufacturer's specification is not available and the superheat is between 4°F and 25°F (inclusive), then the system **passes** the metering device criterion.
    b. For the HERS Rater inspecting the system, if the superheat is between 3°F and 26°F (inclusive), then the system **passes** the metering device criterion.

5.1.8 RA3.2.3 Alternate Charge Measurement Procedure

This section specifies the alternate charge measurement procedure. Under this procedure, the required refrigerant charge is calculated using the Weigh-In Charging Method.

HVAC installers can use this alternate procedure in conjunction with installing and charging the system in as long as it is in accordance with the manufacturer's specifications. Each unit charged with the Weigh-In Charging Method must be verified by a HERS Rater using one of the standard methods or confirm the self-diagnosis of a CID installed on that unit. HERS Raters shall not use this procedure Alternate Charge Measurement Procedure to verify compliance. . If a completed Addendum to CF-6R-Mech-26 HERS is submitted the local jurisdiction Building Official shall allow the permit to be made final based on verification being done in the future when weather conditions are appropriate.

Split system air conditioners come from the factory already charged with the standard charge indicated on the nameplate. The manufacturer supplies the charge proper for the application based on their standard liquid line length. It is the responsibility of the HVAC installer to ensure that the charge is correct for each air conditioner and to adjust the charge based on liquid line lengths different from the manufacturer's standard.

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7. Appendices

7.1 Appendix A: Intertek Testing Conditions

Test	Description	Date	Conditions	CFM per ton
	UNIT 1			
	Baseline			
1	Baseline Charged to 7 Subcooling	9/16/2010	80/67/95	350
	Undercharge with Evaporator Airflow Variations			
2	Undercharged 21.5% of Nom Charge	9/16/2010	80/67/95	350.8
2a	Undercharged 21.5% of Nom Charge	9/16/2010	80/67/95	378.4
2b	Undercharged 21.5% of Nom Charge	9/16/2010	80/67/95	450
2c	Undercharged 21.5% of Nom Charge	9/17/2010	80/67/95	300.8
2d	Undercharged 21.5% of Nom Charge	9/17/2010	80/67/95	278.8
2e	Undercharged 21.5% of Nom Charge	9/17/2010	80/67/95	216.8
Re 2	Undercharged 21.5% of Nom Charge	9/17/2010	80/67/95	350.8
Re 2a	Undercharged 21.5% of Nom Charge	9/17/2010	80/67/95	402
Re 2d	Undercharged 21.5% of Nom Charge	9/17/2010	80/67/95	270.4
	Undercharge with Restricted Condenser Outflow			
Alt 2	Under21.5% + Restricted Cond Flow	9/17/2010	80/67/95	350
	Undercharge at Low Temperatures with Evaporator Airflow Variations and Condenser Outflow Variations			
3	Under21.5%	9/18/2010	70/58/37	406.4
3a	Under21.5% + Restricted Cond Flow	9/18/2010	70/58/38.5	351.2
3b	Under21.5% + Restricted Cond Flow	9/18/2010	70/58/38.5	451.2
3c	Under21.5% + Restricted Cond Flow	9/18/2010	70/58/38.5	251.2
	Low Temperature Charging Procedure			
3d	Charge to 7 Subcooling + Restricted Cond Flow	9/18/2010	70/58/38.5	350.4

	Low Temperature with Evaporator Airflow and Condenser Outflow Variations			
3e	Low Temp. Correct + Restricted Cond Outlet	9/19/2010	70/58/37	250
3f	Low Temp. Correct + Restricted Cond Outlet	9/19/2010	70/58/37	450.4
3g	Low Temp. Correct Unrestricted	9/19/2010	70/58/37	350.8
3h	Low Temp. Correct Unrestricted bringing up outside temperature	9/19/2010	70/58/62.9	350.4
	Low Temp. Charge Results at Standard Temperatures			
3i	How close is Low Temp. Correct to Correct	9/19/2010	80/67/95	350.4
	Confirm Baseline			
1a	Baseline Charged to 7 Subcooling	9/20/2010	80/67/95	350.4
Test	**Description**	**Date**	**Conditions**	**CFM per ton**
	Overcharge with Evaporator Airflow Variations			
4	Overcharged 10% of Nominal Charge	9/20/2010	80/67/95	350.4
Re 4	Overcharged 18.7% of Nominal Charge	9/20/2010	80/67/95	350
4a	Overcharged 18.7% of Nominal Charge	9/20/2010	80/67/95	401.6
4b	Overcharged 18.7% of Nominal Charge	9/20/2010	80/67/95	450.8
4c	Overcharged 18.7% of Nominal Charge	9/20/2010	80/67/95	300.4
4d	Overcharged 18.7% of Nominal Charge	9/20/2010	80/67/95	250.4
4e	Overcharged 18.7% of Nominal Charge	9/20/2010	80/67/95	220.8
	Overcharge at Low Temperatures with Evaporator Airflow Variations and Condenser Outflow Variations			
5	Overcharged 18.7% of Nominal Charge	9/21/2010	70/58/37	350.4
5a	Over 18.7% + Restricted	9/21/2010	69.8/58/37	350.4
5b	Over 18.7% + Restricted	9/21/2010	69.8/58/37	450.8
5c	Over 18.7% + Restricted	9/21/2010	70/58/37	250.4
	Low Temperature Charging Procedure			

5d	Charge to 7 Subcooling + Restricted Cond Flow	9/21/2010	70/58/37	350
	Low Temperature with Evaporator Airflow and Condenser Outflow Variations			
5e	Proper Charge + Restriction	9/21/2010	70/58/36.9	300.8
5f	Proper Charge + Restriction	9/21/2010	70/58/37	401.6
5g	Proper Charge No Restriction	9/21/2010	69.9/58/37	350.8
	Low Temp. Charge Results at Higher Temperatures			
5h	Proper Charge No Restriction	9/21/2010	70.1/58.1/95	351.2
5i	Proper Charge No Restriction	9/22/2010	79.7/67/95	350.4
	Confirm Baseline			
1b	Baseline Charged to 7 Subcooling	9/22/2010	80/67/95	350
	Non-Condensables			
6	Inside at 1 atm N, Outside with factory weight	9/22/2010	80/67/95	350.4
6a	N 1atm adjust to 7 SC	9/22/2010	80/67/95	350.4
6b	N 20 psig adjust to 7 SC	9/22/2010	79.9/67.3/94.9	350.8
	Confirm Baseline			
1c	Baseline Charged to 7 Subcooling	9/23/2010	79.9/67.3/94.7	350
	Cycling Tests			
7	High Airflow		80/67/95	450
7a	Standard Airflow		80/67/95	350
7b	Standard Airflow with Low Speed Fan Delay		80/67/95	350/216

Test	Description	Date	Conditions	CFM per ton
	UNIT 2			
	Baseline			
8	Baseline Unit 2	9/28/2010	80/67/95.1	349.6
	Restricted Condenser Outflow			

9	Restricted Outflow	9/28/2010	80/67/94.9	350
	Low Evaporator Airflow			
9a	Low Airflow	9/28/2010	79.9/67/95	318.8
	Undercharge			
9b	Undercharged 1 lb.	9/28/2010	80/67/94.9	350
9c	Undercharged 2 lb.	9/28/2010	80.1/67/94.9	350.4
	Low Temperature Restricted Condenser Outflow			
10	Restricted Outflow	9/29/2010	69.9/58/37	350.4
	Low Temperature Charging Procedure			
10a	Recharge Low Temp	9/29/2010	69.9/58/37.1	349.6
	Low Temp. Charge Results at Higher Temperatures			
10b	Proper Charge No Restriction	9/29/2010	79.7/67.3/81.9	350
10c	Proper Charge No Restriction	9/29/2010	79.8/67.2/94.7	350.4
	Confirm Baseline			
8a	Baseline Unit 2	9/30/2010	79.8/67/94.9	350.4
	Overcharge			
11	Overcharge 1 lb.	9/30/2010	79.8/67/95.2	350
11a	Overcharge 2 lb.	9/30/2010	79.9/67.1/95.5	350.4
Re 11a	Overcharge 2 lb.	10/2/2010	79.9/67.3/95.5	350.4
	Low Temperature Charging Procedure			
11b	Recharge Low Temp	9/30/2010	70/58/36.9	350.4
	Low Temperature Unrestricted			
11c	Proper w Free Flow	9/30/2010	70/58/36.9	350.4
	Low Temp. Charge Results at Higher Temperatures			
11d	Proper w Free Flow	9/30/2010	79.8/67.2/82	350.4
11e	Proper w Free Flow	9/30/2010	79.9/67.3/95	350
	Confirm Baseline			
8b	Baseline Unit 2	9/30/2010	79.9/67.6/94.9	350

	Recharge at "SEER" Temperature			
12	Recharge 80/67/82	10/1/2010	79.7/67.2/81.8	349.2
	Subcooling with Restricted Outflow at Low Outdoor Temperature			
12a	Check SC 80/67/37 Restricted	10/1/2010	79.8/67.2/36.9	349.6
12b	Check SC 70/58/37 Restricted	10/1/2010	69.8/58.1/36.5	350.4

7.2 Appendix B: Steady State Test Summaries

Test	Description	Conditions	CFM per ton	Total Capacity	Sensible Capacity	Outside Watts	Sim. Inside Watts	Total Watts	Sens EER	Tot EER	SHR	Sub-cooling	Super-heat
	UNIT 1												
	Baseline												
1	Baseline Charged to 7 Subcooling	80/67/95	350	25891	17667	2046	446	2492	7.09	10.39	0.68	7.3	15.6
	Undercharge with Evaporator Airflow Variations												
2	Undercharged 21.5% of Nom Charge	80/67/95	350.8	23901	16364	2006	447	2453	6.67	9.74	0.68	1	22.7
2a	Undercharged 21.5% of Nom Charge	80/67/95	378.4	24270	16875	2000	482	2482	6.80	9.78	0.70	1	23
2b	Undercharged 21.5% of Nom Charge	80/67/95	450	24230	17437	2018	574	2592	6.73	9.35	0.72	1	23.3
2c	Undercharged 21.5% of Nom Charge	80/67/95	300.8	23371	15266	2010	384	2394	6.38	9.76	0.65	0.9	22.6
2d	Undercharged 21.5% of Nom Charge	80/67/95	278.8	22950	14750	2009	355	2364	6.24	9.71	0.64	0.9	22.2
2e	Undercharged 21.5% of Nom Charge	80/67/95	216.8	21827	13504	1997	276	2273	5.94	9.60	0.62	0.9	20.8
Re 2	Undercharged 21.5% of Nom Charge	80/67/95	350.8	23791	16431	1978	447	2425	6.77	9.81	0.69	1	23.5
Re 2a	Undercharged 21.5% of Nom Charge	80/67/95	402	24020	16844	1999	513	2512	6.71	9.56	0.70	1	24.1
Re 2d	Undercharged 21.5% of Nom Charge	80/67/95	270.4	22906	14911	1995	345	2340	6.37	9.79	0.65	0.9	22.9
	Undercharge with Restricted Condenser Outflow												
Alt 2	Under21.5% + Restricted Cond Flow	80/67/95	350	22558	15560	2298	446	2744	5.67	8.22	0.69	1.3	21.7
	Undercharge at Low Temperatures with Evaporator Airflow Variations and Condenser Outflow Variations												
3	Under21.5%	70/58/37	406.4	17559	13224	873	518	1391	9.51	12.62	0.75	1.9	33.5
3a	Under21.5% + Restricted Cond Flow	70/58/38.5	351.2	22551	16902	1578	448	2026	8.34	11.13	0.75	2.4	22.5
3b	Under21.5% + Restricted Cond Flow	70/58/38.5	451.2	23011	18021	1602	575	2177	8.28	10.57	0.78	2.5	22.5
3c	Under21.5% + Restricted Cond Flow	70/58/38.5	251.2	21090	14899	1554	320	1874	7.95	11.25	0.71	2.3	22.2
	Low Temperature Charging Procedure												
3d	Charge to 7 Subcooling + Restricted	70/58/38.5	350.4	25204	19089	1711	447	2158	8.85	11.68	0.76	7.2	9.7

	Cond Flow												
Low Temperature with Evaporator Airflow and Condenser Outflow Variations													
3e	Low Temp. Correct + Restricted Cond Outlet	70/58/37	250	24043	16916	1639	319	1958	8.64	12.28	0.70	7.1	10.4
3f	Low Temp. Correct + Restricted Cond Outlet	70/58/37	450.4	26102	21005	1712	574	2286	9.19	11.42	0.80	8.5	11.5
3g	Low Temp. Correct Unrestricted	70/58/37	350.8	27782	20176	1084	447	1531	13.18	18.14	0.73	11.8	20.4
3h	Low Temp. Correct Unrestricted bringing up outside temperature	70/58/62.9	350.4	26471	19637	1421	447	1868	10.51	14.17	0.74	10.1	14.6

Test	Description	Conditions	CFM per ton	Total Capacity	Sensible Capacity	Outside Watts	Inside Watts	Total Watts	Sens EER	Tot EER	SHR	Sub-cooling	Super-heat
Low Temp. Charge Results at Standard Temperatures													
3i	How close is Low Temp. Correct to Correct	80/67/95	350.4	26531	17994	2149	447	2596	6.93	10.22	0.68	15.4	17.4
Confirm Baseline													
1a	Baseline Charged to 7 Subcooling	80/67/95	350.4	25386	17479	2068	447	2515	6.95	10.09	0.69	7.3	17.5
Overcharge with Evaporator Airflow Variations													
4	Overcharged 10% of Nominal Charge	80/67/95	350.4	26304	17962	2124	447	2571	6.99	10.23	0.68	15	16.5
Re 4	Overcharged 18.7% of Nominal Charge	80/67/95	350	26448	18041	2256	446	2702	6.68	9.79	0.68	21.7	15.6
4a	Overcharged 18.7% of Nominal Charge	80/67/95	401.6	26921	19068	2256	512	2768	6.89	9.73	0.71	21.8	16.3
4b	Overcharged 18.7% of Nominal Charge	80/67/95	450.8	27248	19918	2259	575	2834	7.03	9.62	0.73	21.8	16.8
4c	Overcharged 18.7% of Nominal Charge	80/67/95	300.4	25670	16798	2204	383	2587	6.49	9.92	0.65	22	16.8
4d	Overcharged 18.7% of Nominal Charge	80/67/95	250.4	24604	15514	2235	319	2554	6.07	9.63	0.63	21.4	15.2
4e	Overcharged 18.7% of Nominal Charge	80/67/95	220.8	23682	14612	2259	282	2541	5.75	9.32	0.62	21.5	16.2
Overcharge at Low Temperatures with Evaporator Airflow Variations and Condenser Outflow Variations													
5	Overcharged 18.7% of Nominal Charge	70/58/37	350.4	28313	20661	1096	447	1543	13.39	18.35	0.73	15.4	17.6

5a	Over 18.7% + Restricted	69.8/58/37	350.4	26693	19921	1631	447	2078	9.59	12.85	0.75	22.2	9.2
5b	Over 18.7% + Restricted	69.8/58/37	450.8	27331	21619	1668	575	2243	9.64	12.19	0.79	23	9.8
5c	Over 18.7% + Restricted	70/58/37	250.4	24556	17176	1600	319	1919	8.95	12.79	0.70	23.7	11
	Low Temperature Charging Procedure												
5d	Charge to 7 Subcooling + Restricted Cond Flow	70/58/37	350	25651	19298	1550	446	1996	9.67	12.85	0.75	7.2	11
	Low Temperature with Evaporator Airflow and Condenser Outflow Variations												
5e	Proper Charge + Restriction	70/58/36.9	300.8	24914	18017	1537	384	1921	9.38	12.97	0.72	7.9	10.6
5f	Proper Charge + Restriction	70/58/37	401.6	25882	20045	1570	512	2082	9.63	12.43	0.77	7.5	11.4
5g	Proper Charge No Restriction	69.9/58/37	350.8	27141	19770	1079	447	1526	12.95	17.78	0.73	11.1	21.3
	Low Temp. Charge Results at Higher Temperatures												
5h	Proper Charge No Restriction	70.1/58.1/95	351.2	21568	16823	2127	448	2575	6.53	8.38	0.78	15.4	17.5
5i	Proper Charge No Restriction	79.7/67/95	350.4	25709	17406	2113	447	2560	6.80	10.04	0.68	13.9	16.15
	Confirm Baseline												
1b	Baseline Charged to 7 Subcooling	80/67/95	350	25225	17251	2055	446	2501	6.90	10.08	0.68	7.5	17.2
	Non-Condensables												
6	Inside at 1 at N, Outside with factory weight	80/67/95	350.4	23817	16044	2064	447	2511	6.39	9.49	0.67	6.4	22.7
6a	N 1atm adjust to 7 SC	80/67/95	350.4	25038	16886	2080	447	2527	6.68	9.91	0.67	7.2	17.3
6b	N 20 psig adjust to 7 SC	79.9/67.3/94.9	350.8	13785	9670	2023	447	2470	3.91	5.58	0.70	7.4	47.1
	Confirm Baseline												
1c	Baseline Charged to 7 Subcooling	79.9/67.3/94.7	350	25745	17155	2045	446	2491	6.89	10.33	0.67	7.5	17.2
Test	**Description**	**Conditions**	**CFM per ton**	**Total Capacity**	**Sensible Capacity**	**Outside Watts**	**Inside Watts**	**Total Watts**	**Sens EER**	**Tot EER**	**SHR**	**Sub-cooling**	**Super-heat**
	UNIT 2												
	Baseline												
8	Baseline Unit 2	80/67/95.1	349.6	27667	19414	2065	446	2511	7.73	11.02	0.70	6.9	16

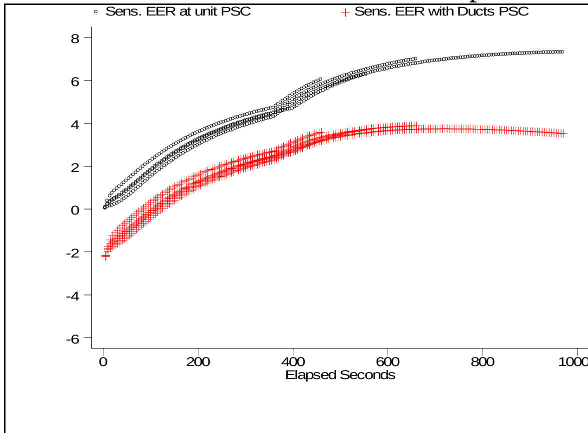
				Restricted Condenser Outflow									
9	Restricted Outflow	80/67/94.9	350	26731	18941	2326	446	2772	6.83	9.64	0.71	11.3	16.1
				Low Evaporator Airflow									
9a	Low Airflow	79.9/67/95	318.8	27409	18557	2059	406	2465	7.53	11.12	0.68	7.4	16.4
				Undercharge									
9b	Undercharged 1 lb.	80/67/94.9	350	26614	18935	2024	446	2470	7.67	10.77	0.71	1.3	18.7
9c	Undercharged 2 lb.	80.1/67/94.9	350.4	25013	18107	1997	447	2444	7.41	10.24	0.72	1.1	23.2
				Low Temperature Restricted Condenser Outflow									
10	Restricted Outflow	69.9/58/37	350.4	23387	18297	1649	447	2096	8.73	11.16	0.78	2.4	19.9
				Low Temperature Charging Procedure									
10a	Recharge Low Temp	69.9/58/37.1	349.6	27019	20563	1637	446	2083	9.87	12.97	0.76	7.6	10.9
				Low Temp. Charge Results at Higher Temperatures									
10b	Proper Charge No Restriction	79.7/67.3/81.9	350	29919	19783	1808	446	2254	8.78	13.27	0.66	11.8	15.8
10c	Proper Charge No Restriction	79.8/67.2/94.7	350.4	28316	19368	2140	447	2587	7.49	10.95	0.68	14.8	16.4
				Confirm Baseline									
8a	Baseline Unit 2	79.8/67/94.9	350.4	27524	19187	2075	447	2522	7.61	10.91	0.70	7.7	16.8
				Overcharge									
11	Overcharge 1 lb.	79.8/67/95.2	350	28299	19598	2254	446	2700	7.26	10.48	0.69	21.3	15.8
11a	Overcharge 2 lb.	79.9/67.1/95.5	350.4	28298	19597	2587	447	3034	6.46	9.33	0.69	33.3	15.4
Re 11a	Overcharge 2 lb.	79.9/67.3/95.5	350.4	28586	19492	2452	447	2899	6.72	9.86	0.68	29.2	15.7
				Low Temperature Charging Procedure									
11b	Recharge Low Temp	70/58/36.9	350.4	26791	20637	1687	447	2134	9.67	12.56	0.77	7.2	10.9
				Low Temperature Unrestricted									
11c	Proper w Free Flow	70/58/36.9	350.4	29352	21727	1082	447	1529	14.21	19.20	0.74	12.1	18.8

					Low Temp. Charge Results at Higher Temperatures								
11d	Proper w Free Flow	79.8/67.2/82	350.4	30188	20336	1806	447	2253	9.03	13.40	0.67	11.8	15.5
11e	Proper w Free Flow	79.9/67.3/95	350	28279	19487	2142	446	2588	7.53	10.93	0.69	14.2	16.2
					Confirm Baseline								
8b	Baseline Unit 2	79.9/67.6/94.9	350	28275	19043	2083	446	2529	7.53	11.18	0.67	7.8	16.6
					Recharge at "SEER" Temperature								
12	Recharge 80/67/82	79.7/67.2/81.8	349.2	29683	19782	1776	445	2221	8.91	13.36	0.67	7.7	14.5
					Subcooling with Restricted Outflow at Low Outdoor Temperature								
12a	Check SC 80/67/37 Restricted	79.8/67.2/36.9	349.6	30521	20249	1790	446	2236	9.06	13.65	0.66	3.5	13.3
12b	Check SC 70/58/37 Restricted	69.8/58.1/36.5	350.4	26773	20311	1647	447	2094	9.70	12.79	0.76	3.5	11.5

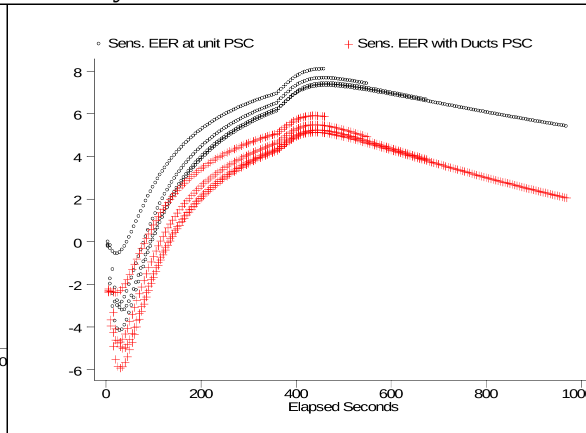
7.3 Appendix C: Cycling Test Summaries

7.3.1 Sensible EER Summary for PSC Unit

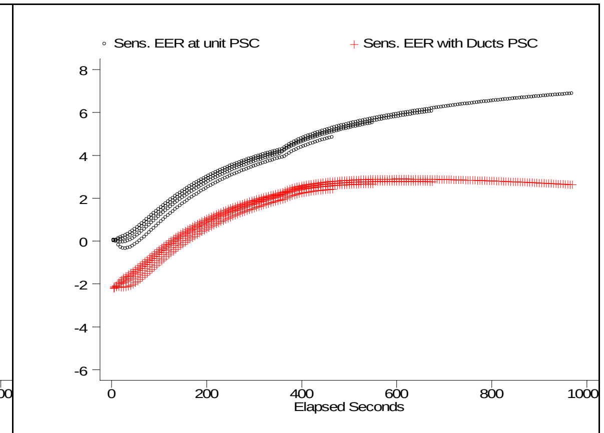
The graphs and table below summarize the maximum Sensible EERs for PSC unit and the time delay at which that maximum occurs. The maximum Sensible EER and optimum time delay for each airflow and duct scenario are shown in ***bold italic.***



350 CFM/ton



450 CFM/ton

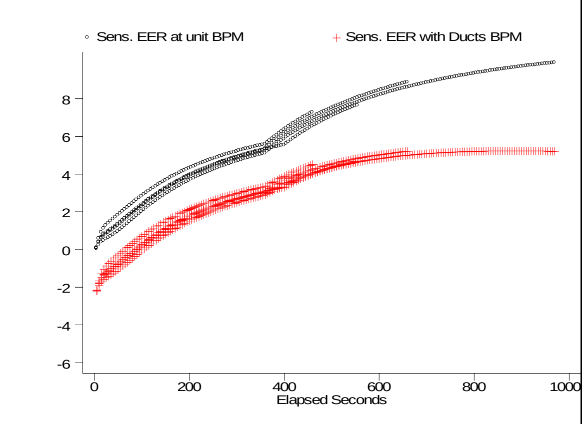


350 - 216 CFM/ton

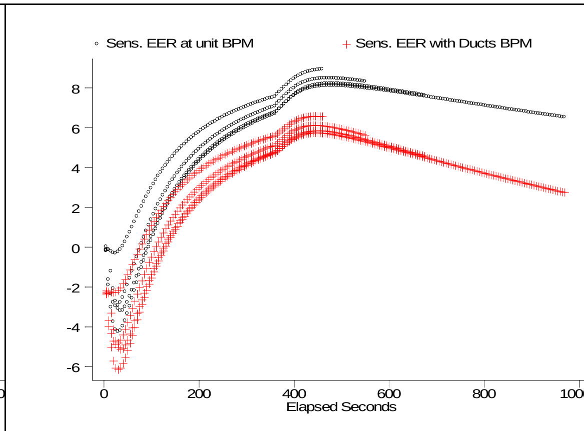
Description		**350 CFM/ton**		**450 CFM/ton**		**350 CFM/ton 216 During Delay**	
Cycle	Condition	Max Sensible EER	Time Delay at Maximum (sec)	Max Sensible EER	Time Delay at Maximum (sec)	Max Sensible EER	Time Delay at Maximum (sec)
Second (105 sec fan delay)	No Ducts	6.01	100	***8.07***	***100***	4.82	105
	With Ducts	3.59	100	***5.91***	***80***	2.41	105
Third (200 sec fan delay)	No Ducts	6.26	195	7.65	100	5.49	190
	With Ducts	3.70	195	5.48	80	2.66	185
Fourth (300 sec fan delay)	No Ducts	6.98	300	7.40	105	6.04	315
	With Ducts	***3.89***	***300***	5.23	85	2.78	240
Fifth (610 sec fan delay)	No Ducts	***7.30***	***610***	7.30	105	***6.86***	***610***
	With Ducts	3.75	360	5.13	80	***2.89***	***250***

7.3.2 Sensible EER Summary for BPM Unit

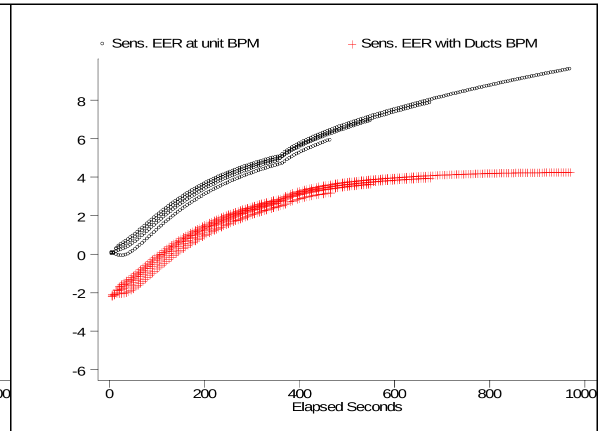
The graphs and table below summarize the maximum Sensible EERs for BPM unit and the time delay at which that maximum occurs. The maximum Sensible EER and optimum time delay for each airflow and duct scenario are shown in ***bold italic.***



350 CFM/ton



450 CFM/ton



350 - 216 CFM/ton

Description		**350 CFM/ton**		**450 CFM/ton**		**350 CFM/ton 216 During Delay**	
Cycle	Condition	Max Sensible EER	Time Delay at Maximum (sec)	Max Sensible EER	Time Delay at Maximum (sec)	Max Sensible EER	Time Delay at Maximum (sec)
Second (105 sec fan delay)	No Ducts	7.25	100	***8.92***	***100***	5.9	105
	With Ducts	4.5	100	***6.58***	***85***	3.18	105
Third (200 sec fan delay)	No Ducts	7.63	195	8.47	115	6.9	190
	With Ducts	4.71	195	6.12	85	3.62	190
Fourth (300 sec fan delay)	No Ducts	8.85	300	8.2	120	7.84	315
	With Ducts	5.21	300	5.85	90	3.94	315
Fifth (610 sec fan delay)	No Ducts	***9.89***	***610***	8.1	115	***9.59***	***610***
	With Ducts	***5.23***	***525***	5.74	85	***4.24***	***590***