Enhanced Refrigeration Diagnostics for an Improved Air Conditioning Tune-Up Program

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ABSTRACT

An enhanced refrigeration diagnostics method is presented that has the opportunity for improving the results of air conditioning tune-up programs. An existing tune-up protocol focused on refrigerant charge and indoor airflow was evaluated based on data collected for 350 small commercial HVAC units. All of the units met the requirements of the tune-up protocol and the data indicate that the number of units with low charge was reduced. Detailed analysis of the test data identified three indicators of reduced operating efficiency – low evaporating temperature (35% of units pre and 22% post), high condensing temperature over ambient (22% pre and 28% post), and incorrect charge (72% pre and 71% post). The pre test results indicate a need for unit repairs in the field and an enhanced protocol is proposed that addresses identified limitations of the evaluated protocol. The enhanced refrigeration diagnostic approach requires the following six measurements: suction pressure, suction temperature, liquid pressure, liquid temperature, ambient temperature, and return air wet-bulb temperature, in addition to an evaluation of indoor airflow. These measurements are used to calculate superheat, subcooling, evaporating temperature, and condensing temperature over ambient, which are then used to assess the performance of the unit. The application of this enhanced protocol would result in improved (collective) unit performance. In particular, the enhanced protocol would benefit units with problems other than charge and indoor airflow and help avoid incorrect charge adjustments.

Introduction

Repair or tune-up of existing unitary air conditioning and heat pump units offers potential opportunity for reducing energy consumption and reducing effective demand for electric utilities. Many of the common problems observed with unitary HVAC equipment, including low airflow and incorrect charge, contribute to reduced operating efficiency. A number of utilities have implemented programs for tune-up of HVAC units and several protocols have been proposed and implemented. One protocol was evaluated in this investigation and an enhanced protocol is proposed to address identified limitations.

Background

A number of investigators have reported problems observed in the field with unitary air conditioning (AC) and heat pump (HP) units. Breuker et al. (2000), AEC (2003), and NBI (2004) have reported commercial unit field problems. Downey and Proctor (2002) and Proctor (1997) have reported residential unit field problems. The most common problems for commercial units are incorrect charge, low airflow, economizer problems, and thermostat or control problems. In addition to these common problems, Rossi (2004) reported that 6% of 1468 refrigeration circuits tested (includes commercial and residential units) had condenser heat transfer problems and 10% required major repairs (e.g., restriction or compressor replacement).

The impact of incorrect charge and low airflow on equipment performance has been reported by a number of investigators; however, other problems are not as well documented. Breuker et al. (2000) report that a 28% blockage of the condenser results in a 14% reduction in efficiency and a 20% increase in pressure drop associated with a liquid line restriction results in 9% reduction in efficiency. Houghton (1997) reported a 16% reduction in efficiency for a dirty condenser coil that raises the condensing temperature from 95°F to 100°F.

Test protocols have been developed that focus on verification of indoor airflow and refrigerant charge. A common test protocol that focuses on indoor airflow and refrigerant charge evaluation and adjustment is prescribed by CEC (2005) for verification of new residential AC and HP unit installations. This test protocol has also been applied to tune-up programs applied to existing units. Energy Market Innovations, Inc. (2004) presents a protocol based on refrigerant charge optimization and economizer operation optimization. Proctor et al. (2003) report on the evaluation of a commercial and residential tune-up program that includes charge analysis and airflow analysis; however, the report does not include a detailed assessment of the unit performance after the tune-up. Their analysis of the impact of refrigerant charge on the unit performance was based on the nameplate charge and the charge adjustment.

Tune-up Protocol

An existing tune-up protocol was implemented for small commercial units with a maximum nominal cooling capacity of 7 tons, no economizers, and only one compressor per unit. The protocol focuses on indoor airflow and refrigerant charge evaluation and adjustment and the procedures are outlined below.

Indoor Airflow

The airflow verification protocol is based on a temperature split test. The temperature split method uses the return air dry-bulb temperature (RA) and supply air dry-bulb temperature (SA) to determine a temperature split (RA-SA). A target temperature split value is determined from a table based on return air dry-bulb temperature and return air wet-bulb temperature. The measured value must be within ±3°F of the target value to pass the test; however, a high airflow rate, indicated by a low temperature split, is allowed in the post test.

Refrigerant Charge

The charge verification protocol is based on a superheat test or a subcooling test depending on the expansion device. A superheat test is used for a fixed orifice (FO). A target superheat value is determined from a table based on outdoor ambient (condenser entering air) temperature and return air wet-bulb temperature. The measured value must be within ±5°F of the target value to pass the test. The charge verification test for a thermal expansion valve (TxV) unit is based on subcooling. A target subcooling value is determined based on the manufacturer's recommendation for the unit. The measured value must be within ±3°F of the target value to pass the test. The test protocol requires that the temperature split airflow test and the charge test be repeated until both pass with the unit in the same condition.

Measurements

Measurement requirements are summarized in Table 1 for the charge verification test. Additional data were collected to allow a more comprehensive performance evaluation of the refrigeration cycle and the data requirements are indicated in Table 1 as "Enhanced Protocol". The application of these measurements is discussed in the following section.

Minimum requirements for the measurement instruments are summarized in Table 2. Refrigeration cycle measurements (pressures and temperatures) were collected using a service technician tool with pressure sensors and thermistor or thermocouple temperature sensors. The tool interfaces with a PDA that runs software that samples data from the sensors and stores the data. Return air and supply air measurements (temperature and humidity) were made using a handheld instrument with a combination temperature/humidity probe that can be inserted into the air duct, and data were manually entered into the PDA. All measurements met the requirements in Table 2.

Table 1. Charge Test Measurement Requirements

Measurement	Charge Test for FO Unit	Charge Test for TxV Unit	Enhanced Protocol Refrigeration Test
Suction pressure (SP)	X		X
Suction temperature (ST)	X		X
Liquid pressure (LP)		X	X
Liquid temperature (LT)		X	X
Outdoor ambient temperature (OAT)	X		X
Return air wet-bulb temperature (RWB)	X		X

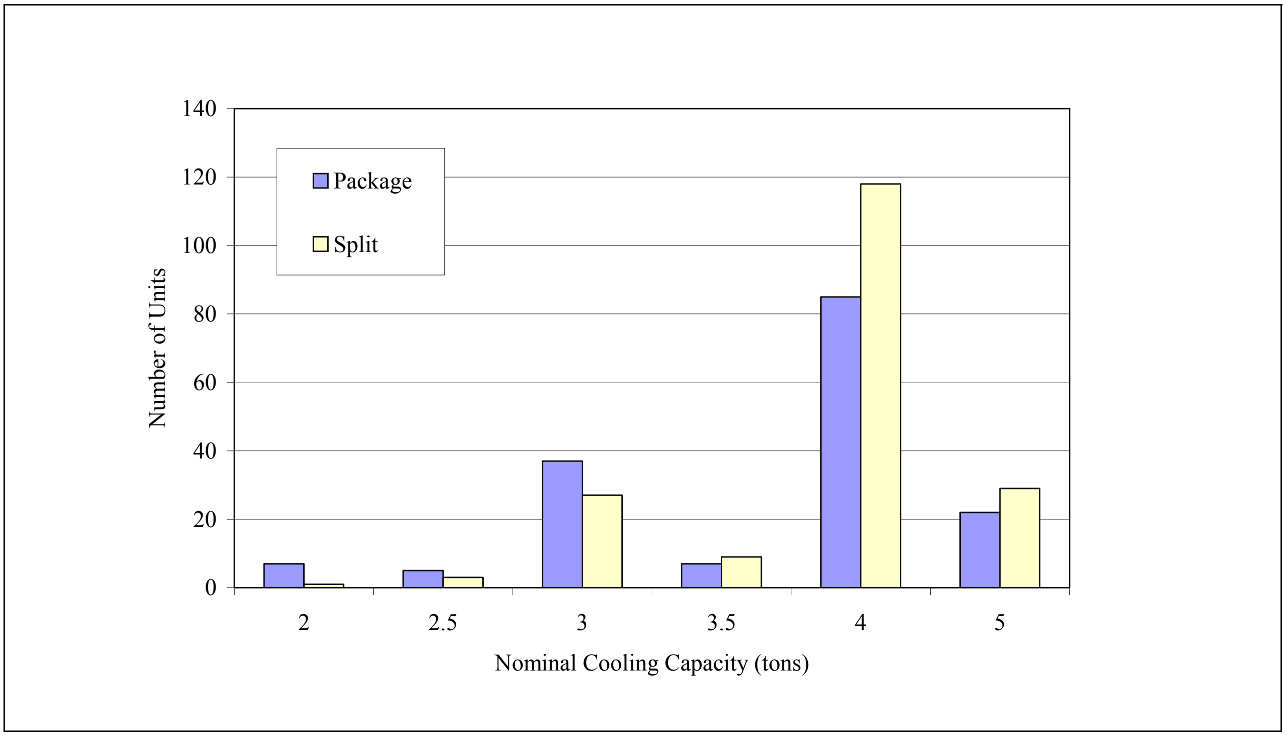
Table 2. Measurement Instrument Requirements

Measurement	Minimum Accuracy	Minimum Resolution
Temperature	±(0.1% of reading + 1.3°F)	0.2°F
Relative humidity	±3% RH	±1% RH
Refrigerant pressure	±3%	

Results

Complete data sets were collected for 350 units and were included in the analysis. The distribution of units by nominal cooling capacity and equipment type (package or split) is presented in Figure 1. All of the units have a fixed orifice expansion device. All the test sites are located in California and the outdoor temperature varied across the 350 tests from 55°F to 94°F. 61 units passed the pre test requirements and therefore had no adjustments. The remaining 289 units did not pass the pre test requirements and had charge and/or airflow adjustments. All of the units passed the charge post test (superheat requirement); however, two units had high airflow on the airflow post test. In summary 289 units of the 350 tested had tune-ups that met the requirements of the tune-up protocol.

Figure 1. Unit Cooling Capacity Distribution (350 units)



The refrigeration cycle data were further analyzed to assess the overall performance of the units. This included an analysis of evaporating temperature (ET), superheat (SH), subcooling (SC), and condensing temperature over ambient (COA). The performance parameters are defined in Table 3.

Table 3. Performance Parameters

Parameter	Calculation
Evaporating temperature (ET)	ET calculated from SP using refrigerant data
Condensing temperature (CT)	CT calculated from LP using refrigerant data
Condensing temperature over ambient (COA)	COA = CT – OAT
Superheat (SH)	SH = ST – ET
Subcooling (SC)	SC = CT - LT

Evaporating Temperature

The calculated evaporating temperature (ET) is based on measurement of the suction pressure (at the compressor), and provides an indication of the temperature of the evaporator. A low evaporator temperature can result in frosting of the coil and reduced system efficiency. The distribution of units by evaporating temperature is presented in Figure 2 and indicates a significant number of units have low evaporating temperature both before and after the tune-up. The cumulative number of units with evaporating temperature below a given threshold is presented in Figure 3. If a recommended low limit of ET is defined as 28°F, 35% of the pre-test units would be classified as unacceptable compared with 22% of the units after the tune-up. Possible causes of low evaporating temperature are evaporator (low-side) heat transfer problem (e.g., low indoor airflow), a liquid line restriction, and low charge. The net improvement in ET for the group of units is probably due to improvements in indoor airflow and charge. The tune-up protocol does not consider evaporating temperature as an important performance index or address liquid line restriction problems.

Figure 2. Evaporating Temperature Distribution

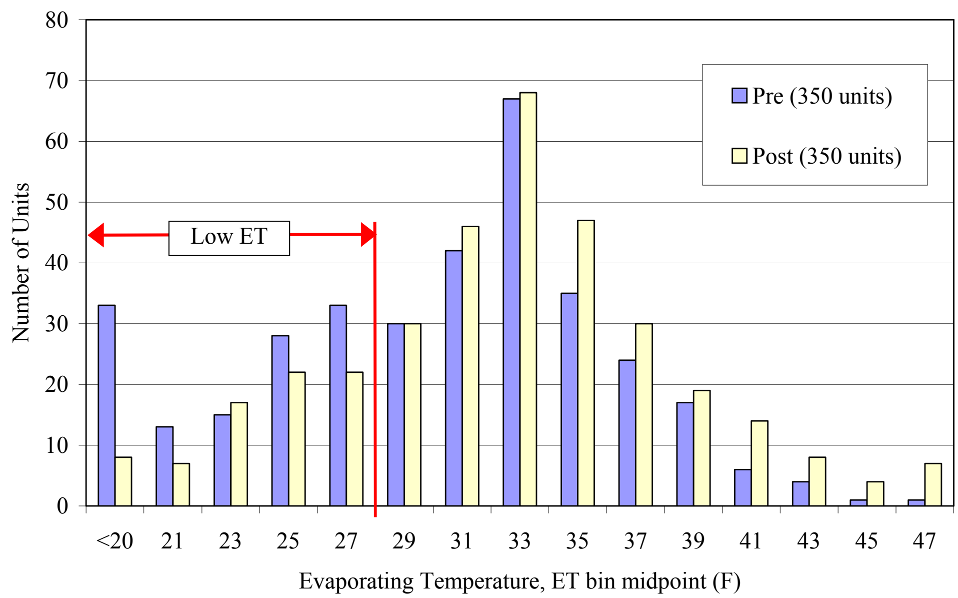
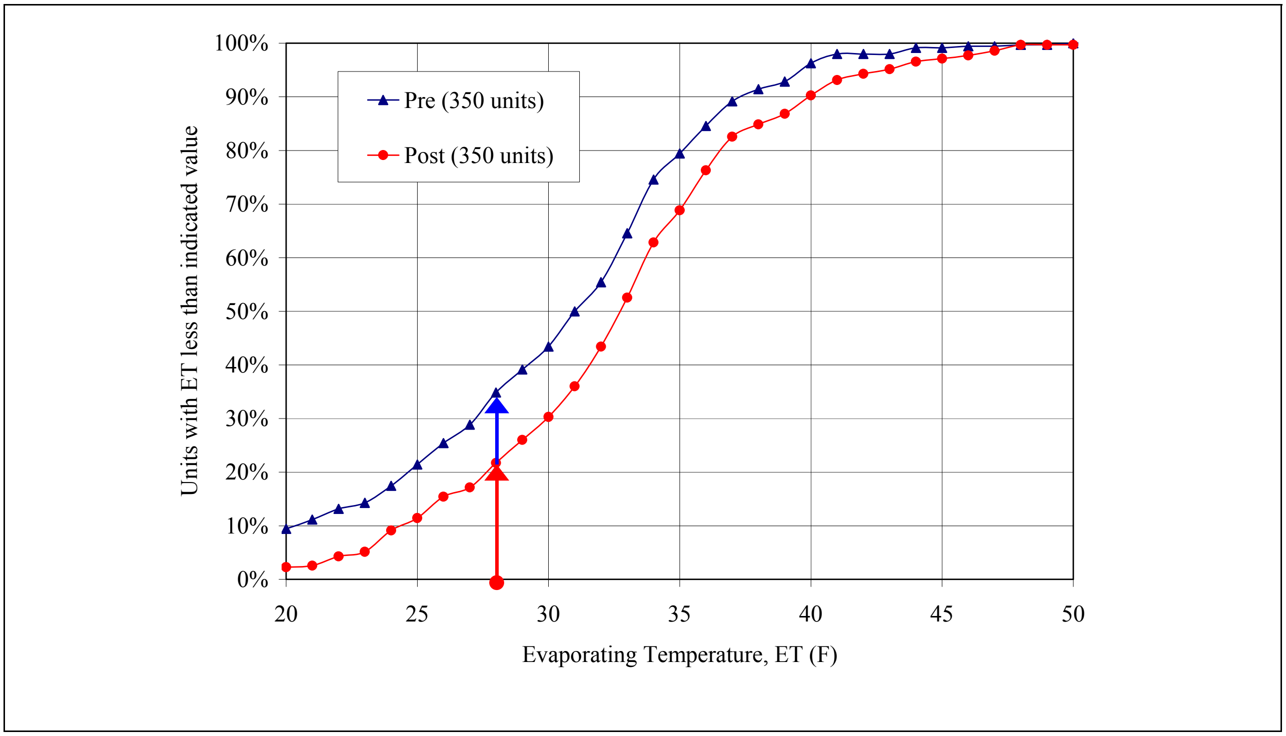


Figure 3. Units with Low Evaporating Temperature



Condensing Temperature over Ambient

A hot condenser as indicated by a high condensing temperature over ambient (COA) can also contribute to reduced system efficiency. The distribution of units by COA is presented in Figure 4 and indicates a significant number of units have hot condensers both before and after the tune-up. The cumulative number of units with COA above a given threshold is presented in Figure 5. If a recommended high limit of COA is defined as 30°F, 22% of the pre-test units would be classified as unacceptable. This number increases to 28% of the units after the tune-up. Possible causes of high condensing temperature over ambient are condenser (high-side) heat transfer problem (e.g., dirty condenser coil), high charge, and non-condensable gas in the system. The net increase in the number of units with high COA is probably due to charge addition. The tune-up protocol does consider condensing temperature as a performance index or address high-side heat transfer problems or refrigerant problems like non-condensable gases.

Figure 4. Condensing Temperature over Ambient Distribution

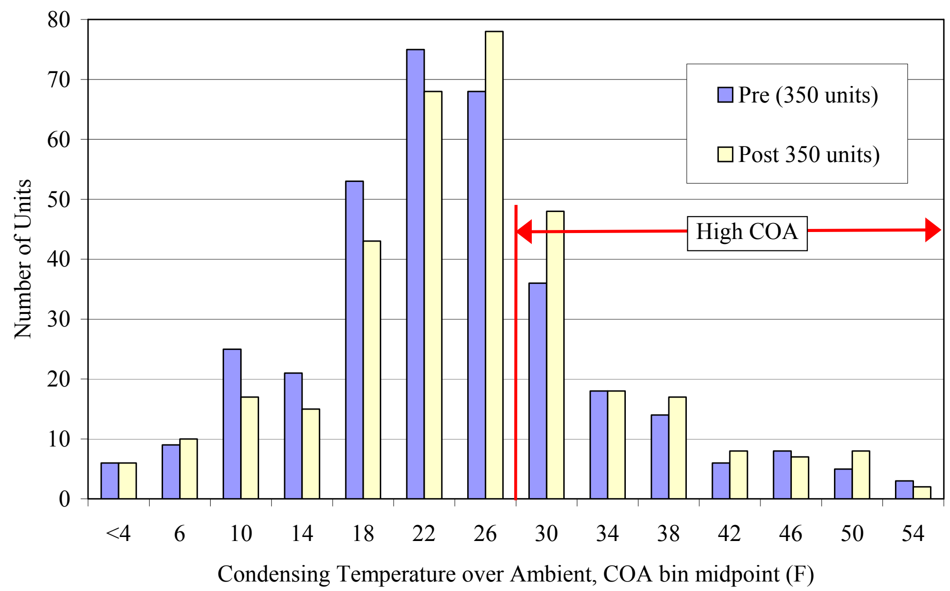
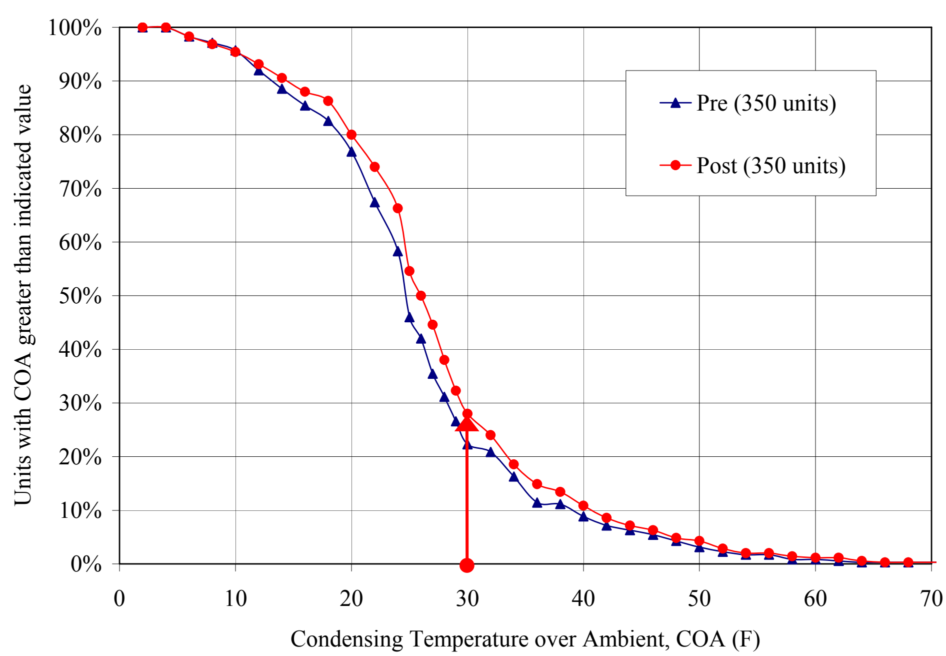


Figure 5. Units with High Condensing Temperature over Ambient



Refrigerant Charge

The tune-up protocol under evaluation includes a basic charge verification test that was designed by equipment manufacturers for use during installation of new units that do not have problems other than charge. In particular, the superheat charge test for FO systems can be biased by other system faults that impact superheat (e.g., liquid line restriction). The following discussion is focused on FO units since there was only one TxV unit in the test group. Temple and Hanson (2003) and Temple (2004) have proposed a charge evaluation method based on measurement of both superheat and subcooling. They presented data indicating that a system with a normal charge state operates at points along a subcooling/superheat line as the driving conditions vary. A representative "Normal" line, based on several sets of experimental data and a nominal operating point of 12°F superheat and 10°F subcooling, is presented in Figure 6. A high charge and low charge line are also included based on a superheat band of ±8°F (effective subcooling band of ±4°F). The pre test and post test data for the 289 units with both tests are included in the figure as a means of assessing the charge state. Points above the high charge line would be evaluated as having high charge. A tabulation of the data is presented in Figure 7 and indicates the initial charge state of the units as follows: 28% OK, 31% high, and 41% low. The charge state of the units after tune-up is as follows: 29% OK, 45% high, and 26% low. Comparing the pre and post conditions, the number of units with low charge is reduced significantly; however, the number of units with high charge is increased. The impact of the high and low charge band was evaluated and the results are presented in Figure 8 for the post data. It can be observed that even with a wide band of ±12°F of superheat, there are still only 41% of the units identified as correct charge.

Evaluation of Current Protocol

The following limitations of the tune-up protocol have been identified:

1. It does not address cold evaporators as a potential problem.
2. It does not address hot condensers as a potential problem.
3. For a FO unit it encourages the use of charge to correct a superheat problem when other faults may be contributing. This can result in high or low charge when other faults exist.
4. It is not sufficiently effective at improving unit performance (from utility or customer perspective). Several conditions that impact efficiency are not addressed.
5. Use of the protocol can result in overestimating energy savings associated with tune-ups since calculations based only on charge adjustment typically assume the final unit charge state is the nominal charge (desired charge), not the actual charge and that there are no other faults.

Figure 6. Refrigerant Charge Assessment

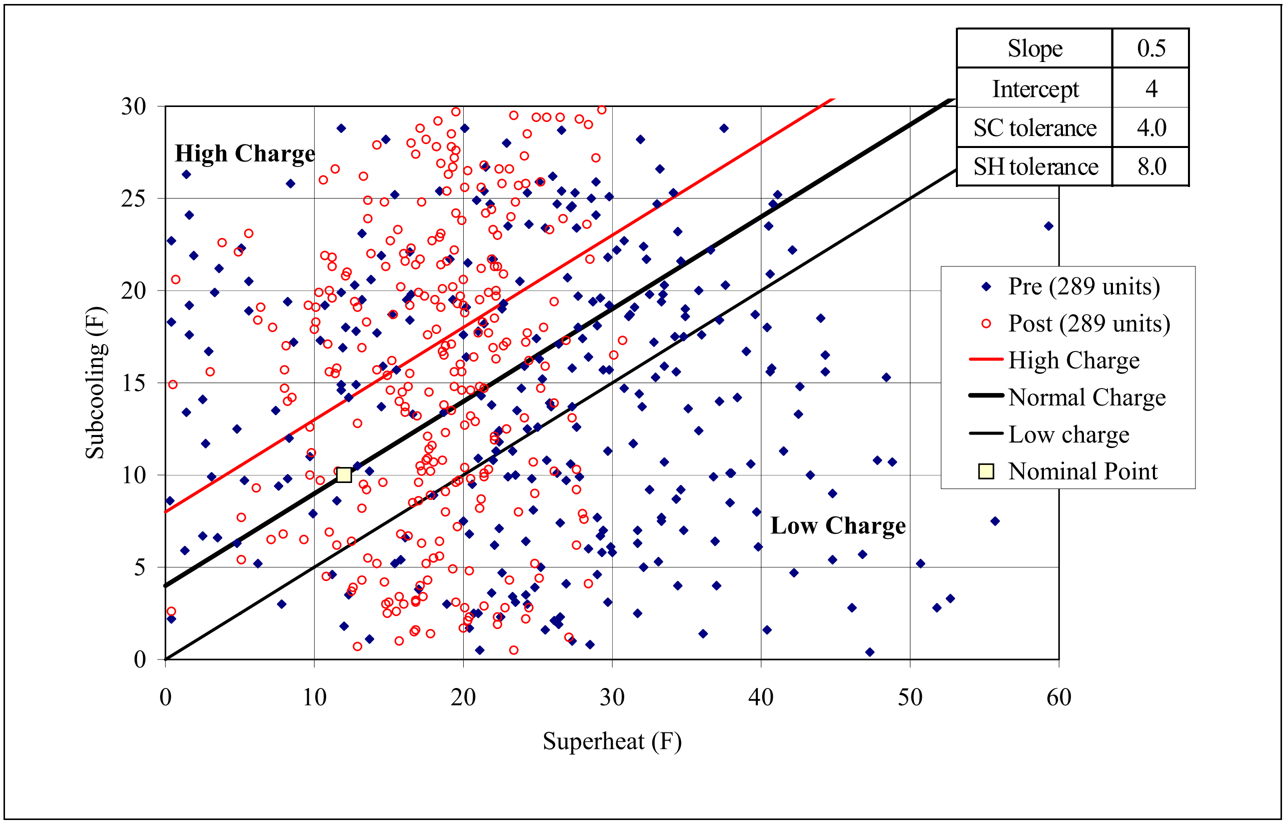


Figure 7. Refrigerant Charge Evaluation

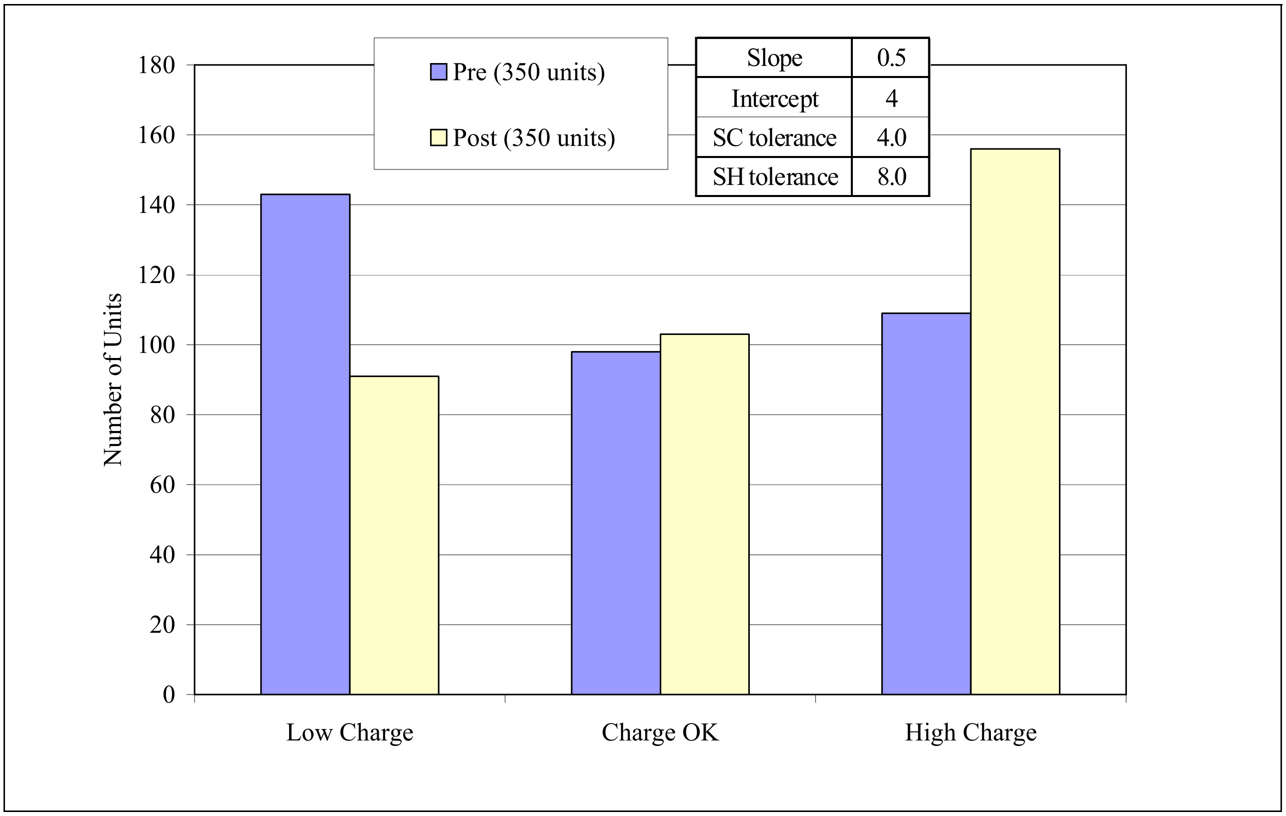
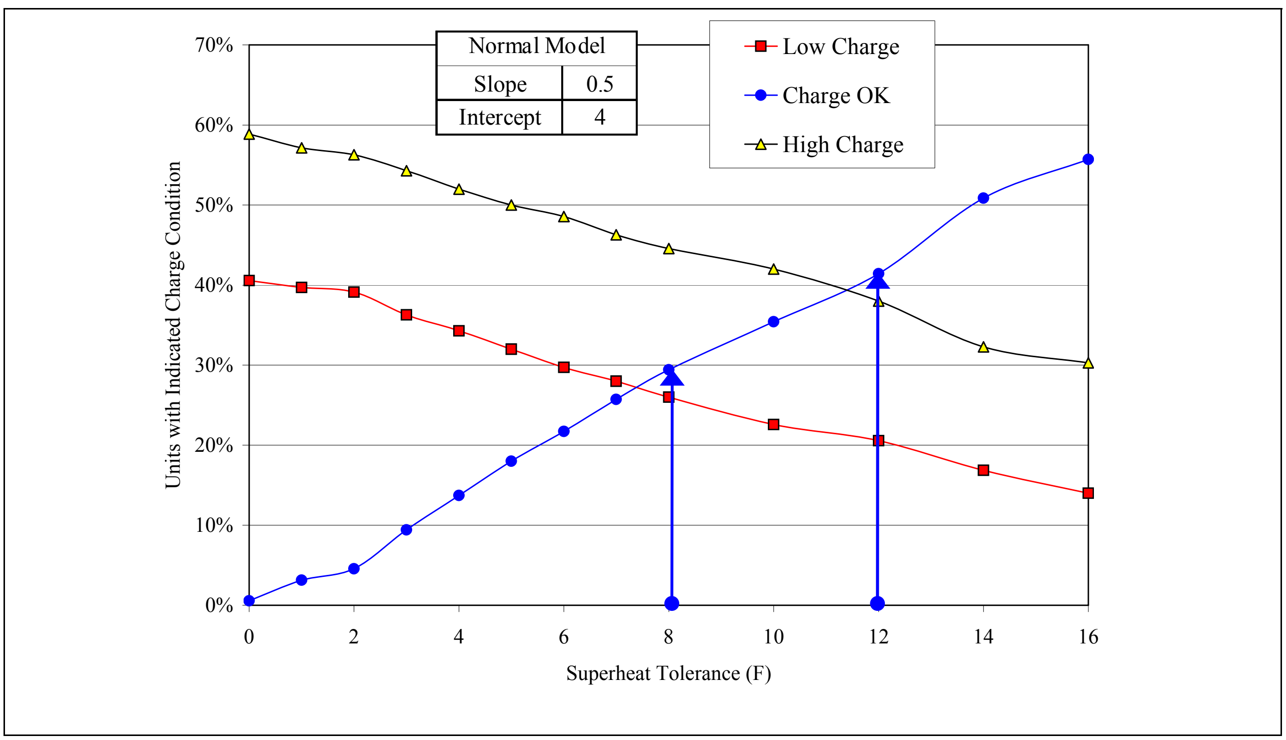


Figure 8. Units with Refrigerant Charge Problem (Post, 350 units)



Proposed Enhanced Protocol

An enhanced tune-up protocol is proposed to improve on the existing protocol and address the identified limitations. The enhanced protocol includes the following components:

1. Evaluate indoor airflow using the existing protocol (direct airflow measurement or temperature split method).
2. Evaluate ET and address problems prior to final charge assessment.
3. Evaluate COA and address problems prior to final charge assessment.
4. Evaluate refrigerant charge with an improved charge diagnostic using both subcooling and superheat.

The enhanced protocol considers that the system performance may be significantly impacted by faults other than incorrect airflow and charge. The proposed protocol is intended to address two system operating conditions that are not directly addressed by the current protocol – cold evaporator and hot condenser. Both of these operating conditions contribute to reduced efficiency. Breuker et al. (2000) and Houghton (1997) have quantified the impact of condenser faults on efficiency. The enhanced protocol also includes an improved charge diagnostic that is intended to prevent adjustment of charge in response to superheat (FO) or subcooling (TxV) when the measurement may be impacted by other faults. Using both subcooling and superheat measurements provides a charge diagnostic with reduced sensitivity to other system faults.

Although limits were suggested in this paper, additional investigation may be required to define the programmatic pass/fail criteria for the ET and COA tests. Likewise, additional investigation may be required to define the target superheat/subcooling line and the allowable tolerance for determining acceptable charge level. The proposed enhancements are applicable to tune-ups for both FO and TxV units.

Conclusions

An existing tune-up protocol was implemented for 350 small commercial units and the results were analyzed. All of the units met the requirements of the tune-up protocol and the data indicate that the number of units with low charge was reduced. However, other problems were identified by a detailed analysis of the data. Problems that contribute to reduced efficiency were observed in the post data – those causing low evaporating temperature (22% of units) and high condensing temperature over ambient (28% of units), and specifically incorrect charge (71% of units). The tune-up actually increased the number of units with high condensing temperature over ambient and high charge. The test results illustrate the need for improvements in the existing tune-up protocol. The existing protocol achieves improvement in performance for only a limited number of units. The proposed enhanced protocol addresses key limitations of the existing protocol and includes a check for evaporating temperature, a check for condensing temperature over ambient, and an improved charge verification test, requiring both superheat and subcooling evaluation for TxV and FO units. The application of this enhanced protocol would result in improved (collective) unit performance by addressing operating conditions that are indicators of reduced efficiency. In particular, the enhanced protocol would benefit units with problems other than charge and indoor airflow and help avoid incorrect charge adjustments.

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